The TREND IN ENGINEERING

at the University of Washington

In this issue:

- Current Research Amplified by Electronic Project
- What Does the Theory of Plasticity Offer to the Designer?
- Research Corporation and University Sign Agreement
- Evaluation of Earthquake Hazard to Foundations
- Road Builders to Meet
- Recovery of Alumina from Oregon Laterites
- Power-Rating Tests of Worm Gears

January, 1951

VOL. 3, No. 1

SCIENCE is intimately concerned with space, time, the physical world and the nature and origin of life; it is more reserved in its approach to the concepts of good and evil, a Great Pattern or Supreme Being, and the problems of unity and duality. It is certainly concerned with the mind and the sources and validity of knowledge, with rationalism, empiricism and pragmatism, and it makes vital contributions to idealism. Even though it avoids attempting to define a man's soul, science has wide areas of interaction with the higher values of life in aesthetics and ethics or moral values. . . . The essence of science lies in the spirit of the men who carry it forward, and for them science is not primarily a rational pursuit; it is in broad terms an aesthetic pursuit, and its satisfactions are primarily satisfactions of the spirit.

"There has been too much talk about the neutrality of science in ethics and moral values. The writers who have publicized this view have greatly misled and even frightened the public, and they have acted on a misconception. The body of organized facts in science may be ethically neutral in a special sense, but this is only one side of the picture. Science is a living, growing, changing thing, and it is impossible to consider any living thing as separate from its environment. I believe that ethical and moral values are essential elements in the nutritional medium of social environment in which science grows. If these elements are distorted or weak the growth will be stunted; without them growth cannot take place and the whole fabric of scientific methods and materials will wither and die. Let me read a quotation or two from a talk by Professor A. V. Hill a year ago in England. He was speaking on the Responsibilities of Scientists in Modern Society.

> If standards of truthfulness, frankness and integrity are relaxed, either for political motives or for private ambition and gain, if fraud, dishonesty and self-deception are not denounced, if mistakes are not honestly acknowledged and corrected, if propaganda is accepted in place of fact: if the common prestige and good-will of science are prostituted for base, sectional or selfish purposes: if secrecy or secretiveness is accepted as a normal condition of scientific work: if age, prestige or authority, if race or nationality, is allowed to hinder freedom of intercourse, or equality and interchange of ideas, between scientists of honesty and good will anywhere in the world: if there is widespread failure to recognize an unbreakable obligation—as it should be—that the benefits of scientific discovery must be regarded as a sacred trust for mankind: then, science itself may become impossible as a calling for free and honest men, while its exploitation for sectional gain, or national aggrandizement, may lead to conflict and destruction instead of cooperation and welfare. . . .

"It is no accident that science has reached its present stature in the environment of Western culture, in which all ethical values focus on the end in view as a person, a human individual. The spirit of science is full of moral values, and at the core of it all lies a profound respect for the spirit and mind of the single, free individual. . . . If you accept the idea that science is neutral in ethics you are ignoring vital factors which are intrinsic parts of the whole structure of science, and your predictions will be wrong. The history of science is the history of one of the great endeavors of the spirit of mankind. It is clearly an important branch of the humanities today."

—From the address of Merle A. Tuve, "Science and the Humanities," on the occasion of the Research Corporation Award, November 19, 1947.

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;

(2) to undertake extended research and to publish reports on engineering and scientific problems;

(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgy, Ceramics
9. Physics Standards and Tests

The control of the Station is vested in a Station Board consisting of the President of the University, the Dean of the College of Engineering as chairman, the Director of the Station, and members of the faculty, representative of the administrative divisions. The Board determines the character of the investigations to be undertaken and supervises the work.

The Station offers a substantial number of research fellowships to highly qualified graduate students who work under the direct supervision of the faculty of the various divisions. The results of the investigations are published in the form of bulletins, technical notes, and reports. Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station. Requests for copies of the publications and inquiries for information on engineering and industrial problems should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

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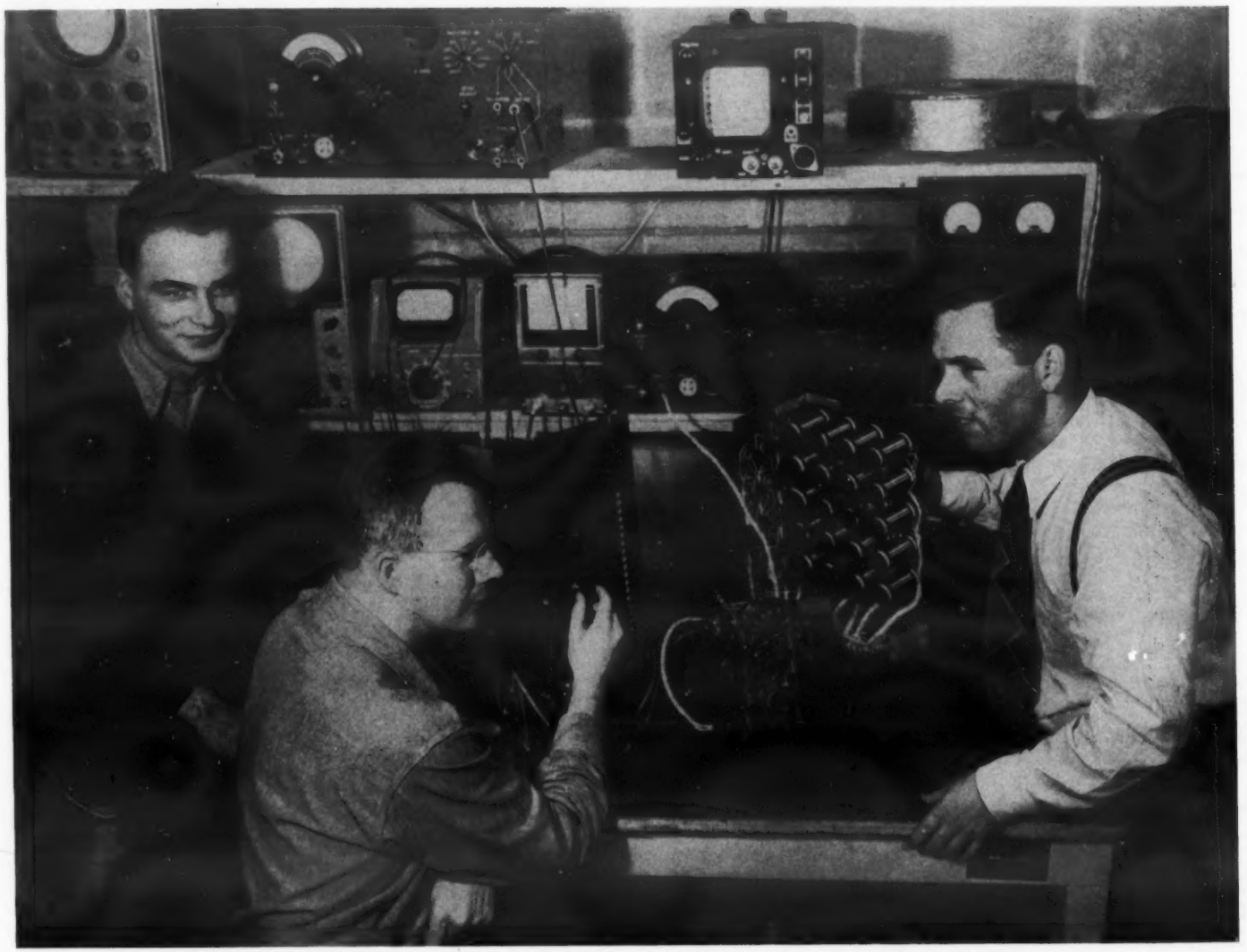
COVER

Members of Project 81 crew adjusting eccentricity of the mechanical vibrator at the Snohomish site. *Left to right:* Harold Frazier, Harold Mason, K. H. Chang.



ELECTRONIC SERVICE GROUP (*left to right*): P. JACQUEMIN, L. BARTER, A. B. JACOBSEN. (Mr. Moore could not be present.)

Current Research Amplified By Electronic Project

W. Ryland Hill

Associate Professor of Electrical Engineering

IN TROUBLE? Call Project No. 28. Need to know when a woodborer is dead, how to pick raspberries acoustically, or how to set up an electron microscope? Just call Andy.

Electronic Controls and Measurements Project No. 28 was set up several years ago under the supervision of Andy Jacobsen to solve just such problems. By now the accomplishments of his group make interesting reading and provide an insight into the many studies undertaken by the Engineering Experiment Station.

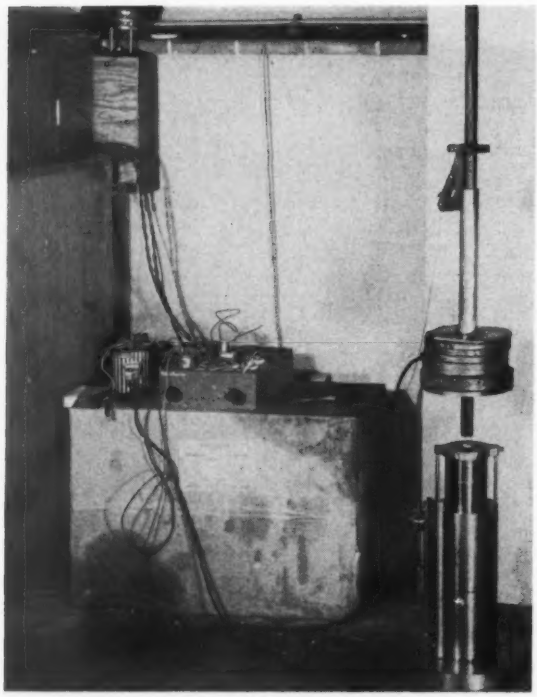
Recognition of the need for a service organization came after the war, with the sudden expansion of the Experiment Station activities. Graduate students in the various branches of engineering found that electronics had "grown up," and that many of the measurements necessary in a mechanical, a chemical, or a civil engineering research study were best made with electrical instruments. Where formerly mechanical systems had traced out the vibratory response of a bridge model, the new strain-gage bridges with amplifiers and electrical recorders provided a much more sensitive and accurate recording system. In chemical engineering research, electrical indicating systems were now measuring hydrogen ion concentration, and electronic controls were watching and stabilizing the variables of temperature, applied voltage, or current.

At the University of Washington, it became apparent that all too often research work was being handicapped by lack of knowledge of the possibilities of electronic measuring, recording, or control systems, and that a civil engineer, for instance, could hardly be expected to find time to acquire an electronic background and effectively solve a difficult measuring problem. Consequently, the Electrical Engineering Department was persuaded to relinquish half of Instructor Andrew Jacobsen's time to permit him to establish Project No. 28 and take over many of the measurement and control headaches of the other research projects. At present the group consists of Mr. Jacobsen who heads the group and provides many of the astoundingly Rube Goldbergian ideas, LeRoy D. Barter, with degrees in both aeronautical and electrical engineering, who not only provides many of the mechanical ideas but also works out the electrical theory to show that the particular gadget can't possibly work, and two part-time students, Herman Moore, a senior in E.E., and Pierre Jacquemin, a graduate student in M.E. The two part-time men do much of the routine electrical and mechanical construction to relieve Mr. Jacobsen and Mr. Barter and permit them more time for design and consultation. (See frontispiece.)

The work of the project takes three forms: (1) advisory, in which the group suggests solutions to measuring and control problems and may help in the selection of commercial equipment to suit the situation or may merely provide the necessary circuit diagrams for construction of the equipment; (2) construction, in which the group not only helps to solve the problem but actually constructs the specialized equipment to aid the research group, often including a number of items not commercially available for which there is considerable demand; (3) trouble shooting, which includes for instance, helping the research groups to iron out "bugs" in the measurement and control features of a setup, and servicing all the electron microscopes on the campus. Sometimes this work leads to suggestions regarding the actual solution of the fundamental research problem, although such a function, of course, is not primarily that of the group.

Among the special pieces of equipment developed by the group is the basic amplifier described in *The Trend* for October, 1949. This versatile instrument serves as the intermediate link between the pickup device, a strain-gage for example, and the recording or indicating system such as a meter, a recording instrument, or a cathode-ray oscilloscope. It not only performs the functions of amplification, but it also supplies the auxiliary a-c and d-c power for strain or pressure transducers. The amplifiers are particularly stable and it is interesting to know that Mr. Barter worked out a new method of analyzing the feedback circuits used to provide stability. As a result the circuits have particularly good low-frequency and transient response.

Another noteworthy job was the construction of a 60-gage strain indicator and recording system for the 2,400,000-lb testing machine in More Hall. The installation is unusual for the number of gages and for the remote control featuring the use of stepping relays somewhat similar to those used in a dial telephone system. Again, after conferring for some time with the Mechanical Engineering Department on measuring problems in testing gears, the group has built an instrument, using the basic amplifier, which



TESTING THE PERFORMANCE OF AN OLEO STRUT

will indicate the torque input and output to the gears.

The work of Project 28 touches many fields. In the field of control, for example, the group has made a number of power supplies for chemical engineering which accurately control the voltage or current supplied to a research setup. These have proved very useful. For mechanical engineering they also built a sensitive thermopile used to control the power input and thus the temperature of the guard surfaces required to produce one-dimensional heat flow in a device for measuring thermal conductivity. This is much faster and more accurate than a hand adjustment, making it well worth while despite the availability of graduate students to perform the operation. A variation of this same system is to be used in chemical engineering to control the temperature of a large tank by controlling the heating power. In this particular case the majority of the power will come from a fixed source and the control system will handle only the incremental power required to keep the system at exactly the right temperature. This is a simple example of using finesse instead of brute force to accomplish the desired result.

Another control problem dealt with speed control of the motor used in a "thumper" for shaking the earth to investigate wave propagation in soils. (See cover illustration.) In this particular instance the electrical engineers with their knowledge of power radiation from electrical and acoustical vibrating systems were inclined to make suggestions and draw analogies not always welcomed by the civil engineers and probably not always valid in a solid medium, which can carry shear, as compared to an electrical or gaseous medium which has no equivalent property.

One of the most intriguing studies has been in the field of sound. This Experiment Station project dealt with the destruction of wood piles by marine borers, the problem being to destroy the borers in existing piles and to avoid expensive pile replacement. The initial problem was that of killing the borers.

"Why that's easy," said one of the project advisers. "Just drown them!" To drown marine life at first might seem absurd until it is pointed out that salt-water life can be killed by exposure to fresh water. With plenty of fresh water available and a zipper-fitted canvas jacket to surround a pile and permit displacement of the sea water, the next problem became that of knowing when the wood borers were dead. At this point it was discovered that no one could tell precisely when the creatures *were* dead. Life of such a low order can undergo long dormant periods without harm.

Here one of the divers associated with the project provided a clue. "Just listen to 'em chewin'!" At that a call went out to Project No. 28 to find out ways and means of listening to underwater chewing of marine borers. The result was an experimental setup in Fisheries, under the direction of Dr. W. F. Thompson, complete with pile samples equipped with worms known to be alive. Then with a special waterproofed microphone the listening began. One by one the stray sound sources were eliminated and the sensitivity of the microphone increased. Each time new extraneous sounds appeared and were in turn removed until at last nothing remained but the drip of a faucet in a distant room. But still the worms remained silent and as yet no one knows how to tell whether a borer is dead or only dormant.

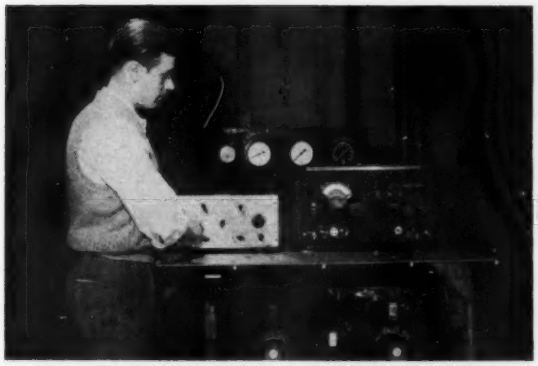
In a similar study a special underwater microphone was constructed to investigate the noises, if any, made by a swimming fish. Actually a fish probably makes low-frequency pressure variations rather than noise in the usual sense. The purpose of this investigation was to find some way of automatically counting fish running up a stream. In an experimental setup, again it was found that the pressure waves from stray sources caused more indication than the fish. For example, a quarter-inch wave traveling on the surface of the water tank produces a significant output; only after lining the tank walls with absorbent matting and covering the water surface to prevent ripples was it possible to observe any significant disturbances made by the fish. This was

observed under the ideal condition of having the microphone very close to the fish; to attempt to observe acoustically the presence of a fish in a moving stream with the attendant ripples and pressure waves seems impossible. As Mr. Barter expressed it, a fish is a much too efficient swimmer.

In the field of measurements, help with strain-gage installations is an every-day problem. But equally important is the problem of recording and using the information, and it is here that the inventiveness of the group is particularly useful. One interesting example is the automatic decrement recorder used in connection with vibration studies of the model of the Tacoma Narrows Bridge. One way of measuring decrement is to make a lengthy recording of the vibrations, then to find the time intervals required for given fractional amplitude reductions, and from these compute the decrement as a function of amplitude—the information actually desired. This way of determining decrement is cumbersome and very inaccurate for low amplitudes.

The automatic decrement recorder, on the other hand, consisted of an adjustable-gain amplifier and an amplitude measuring unit that automatically increased the amplifier amplification by 10 per cent when the output dropped below a given level. With this arrangement the amplitude slowly dropped until the lower level was reached, at which point the amplification was boosted 10 per cent. The output amplitude then again slowly dropped until after a 10 per cent change the output circuit again increased the amplification 10 per cent and again raised the signal to the former level. This operation repeated produced a record with sudden level changes which clearly defined the periods required for successive 10 per cent drops in input signal or vibration. From these the decrement was easily computed.

These illustrations show the importance of the work done by the members of Project No. 28 and their contribution to the whole research program of the Engineering Experiment Station. Without their aid many of the projects would certainly have been delayed or not completed.



STRAIN-GAGE INDICATOR USED IN WORM-GEAR TESTS
(P. Osborne, Research Fellow in E.E.S.)
(Note basic amplifier designed by Mr. Jacobsen and used as a fundamental unit in many experimental setups.)

What are some of the plans for the future? One is the development of a strain gage from evaporated metal films to provide a sensitive high-resistance unit with a very small surface area. Another dream is a recording device to print numbers rapidly instead of directly tracing amplitudes in curve form. This would reduce the errors produced in attempting to read from recorded curves by substituting an actual printed number corresponding to the amplitude at a given time moment. If realized, it would approach the ultimate in a recording and computing device, one which would collect and digest data into convenient capsule form and permit the project supervisor to spend his time leaning back in an easy chair with his feet on the desk.

SEWAGE WORKS SCHOOL HELD ON CAMPUS

The second biennial Sewage Works School of Western Washington was conducted in More Hall, November 16, 17, under the auspices of the Pacific Northwest Sewage Works Association, the Association of Washington Cities, the Pollution Control Commission, the State Department of Health, and the University of Washington. Campus sponsors were the Department of Civil Engineering and the Division of Adult Education.

Of the 103 registrants, about 60 were operators of sewage-treatment plants, and the rest were consulting engineers, city engineers, and other municipal officials. Although this meeting was scheduled for western Washington, representatives of other regions were present.

The general program included papers and panel discussions directed toward such problems as servicing equipment, industrial waste, creating a market for sewage sludge, administration and accounting, and pollution control. For the afternoon sessions both introductory and advanced groups were instructed in performing laboratory tests and interpreting data.

In 1938 the first combined Water Works and Sewage Works School was conducted at the University of Washington. Later, as public interest increased and officials became more aware of the problems involved, each of the two groups held its own sessions. The number of sewage-treatment plants in the state has increased from about a dozen in 1938 to 125 at the present time.

WHAT DOES THE THEORY OF PLASTICITY OFFER TO THE DESIGNER?

WILLIAM PRAGER

Professor of Applied Mechanics, Brown University

W. Prager

The mechanical behavior of materials in the plastic range is much more complex than that in the elastic range. It is hardly surprising, therefore, that the mathematical theory of plasticity is more complex than the mathematical theory of elasticity. Whereas the more elementary aspects of the latter have been incorporated in the undergraduate curricula of progressive engineering schools, the first is still being completely ignored by most of these curricula. This seems regrettable because students of engineering should be introduced to certain concepts of the theory of plasticity which are bound to influence design practices. To show that these concepts can be presented in an elementary manner is the purpose of these lines.

Let us consider the plane structure shown in Fig. 1. The two-force members OA, OB, OC join the point O to the fixed points A, B, C; the structure is symmetrical with respect to the vertical OB and the load P acts along this axis of symmetry; the bars OA and OC form angles of 45° with the bar OB. We shall assume that the mechanical behavior of the

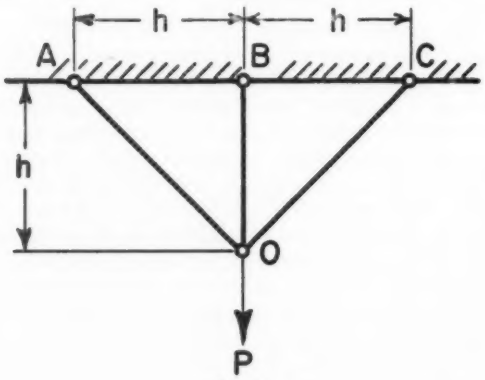


FIG. 1

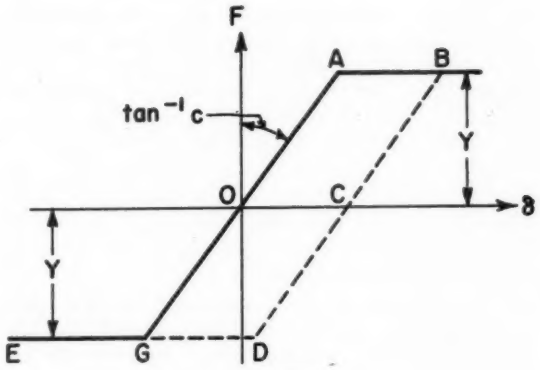


FIG. 2

three bars under axial loads is characterized by force-elongation diagrams of the form shown in Fig. 2: as long as the absolute value of the axial force F is smaller than the "yield force" Y, the infinitesimal change dF of F and the corresponding infinitesimal change $d\delta$ of the elongation δ are related to each other by Hooke's law,

$$d\delta = c\,dF, \tag{1}$$

where $c = l/EA$ is the "compliance" of the bar under consideration, l, its length, A, its cross-sectional area, and E, Young's modulus. When F reaches the values $\pm Y$, the bar is free to "flow plastically" in tension ($F = Y$) or compression ($F = -Y$). If the bar is unloaded after a point such as B in Fig. 2 has been reached by plastic flow in tension, the unloading process is represented by the straight line segment BC which is parallel to the segment OA representing the initial loading. When the load has been completely removed (point C in Fig. 2), the bar exhibits the permanent extension represented by the segment OC. If the bar is now loaded in compression, the force-elongation diagram $CDGE$ is obtained. Figure 2 shows that this elastic-plastic behavior of the bar is defined by two constants: the compliance c and the yield force Y. In the following, we shall denote by c_1, Y_1 the values of these constants for the

bars OA, OC, and by c_2, Y_2 the values for the bar OB. Furthermore, we shall use the notations,

$$\alpha=c_2/c_1, \quad \beta=Y_2/Y_1. \tag{2}$$

In the elastic range (GOA in Fig. 2), a given load P produces uniquely determined values of the forces F_1 (in the bars OA, OC) and F_2 (in the bar OB). These can be obtained from the equations,

$$F_1\sqrt{2}+F_2=P, \tag{3}$$

$$F_1\sqrt{2}-\alpha F_2=0. \tag{4}$$

The first of these expresses the fact that the forces which the bars transmit to the point O must be in equilibrium with the load P. The second equation is obtained in the following manner. On account of its symmetry the structure will deform in such a manner that the bar OB remains vertical. Thus, the displacement of the point O is vertical and has the magnitude δ_2. For the small elongations considered here, the elongation δ_1 of the bar OA produced by this displacement of O is found by projecting the displacement of O on the direction of the bar OA. Thus,

$$\delta_1=\delta_2/\sqrt{2}. \tag{5}$$

Now, in the elastic range, $\delta_1=c_1F_1$, $\delta_2=c_2F_2$. Substituting these values into (5) and using (2), we obtain Eq (5).

In the following, Eq (3) will be called the "equation of equilibrium", and Eq (4) will be called the "equation of compatibility". Solving these equations for F_1 and F_2, we obtain

$$F_1=\frac{\alpha P}{(1+\alpha)\sqrt{2}}, \quad F_2=\frac{P}{1+\alpha}. \tag{6}$$

The "elastic design" of the structure would be based on these formulas: the structure reaches its elastic limit under the load P_e which first produces yielding in one of the bars. Thus, P_e equals the smaller one of the values,

$$\frac{(1+\alpha)\,Y_1\sqrt{2}}{\alpha}, \quad (1+\alpha)\beta Y_1.$$

For $\alpha=1$, $\beta=2$, for instance, one finds

$$P_e=2Y_1\sqrt{2}. \tag{7}$$

To study the mechanical behavior of the structure beyond the elastic limit, we may use the following graphical representation. Using F_1, F_2 as rectangular Cartesian coordinates, we represent the states of stress of the structure by the points of the F_1, F_2 plane (Fig. 3). Since the forces in the bars cannot exceed the yield forces in absolute value, the useful portion of the F_1, F_2 plane is the "yield rectangle,"

$$-Y_1\leqq F_1\leqq Y_1, \quad -\beta Y_1\leqq F_2\leqq\beta Y_1. \tag{8}$$

The equation of compatibility (4) represents a straight line through the origin in the F_1, F_2 plane (line OS_1 in Fig. 3). Within the elastic range of the structure, the "stress point" representing the state of stress under a given load must lie on this line which will therefore be called the "line of elastic states." The stress point S_1 for a given value P_1 of the load P is the intersection of the line of elastic states and the "line of equilibrium for the load P." The latter (line P_1 in Fig. 3) represents Eq (3) in the F_1, F_2 plane. Note that the lines of equilibrium for various values of P are parallel to each other; the distance of the line of equilibrium from the origin O

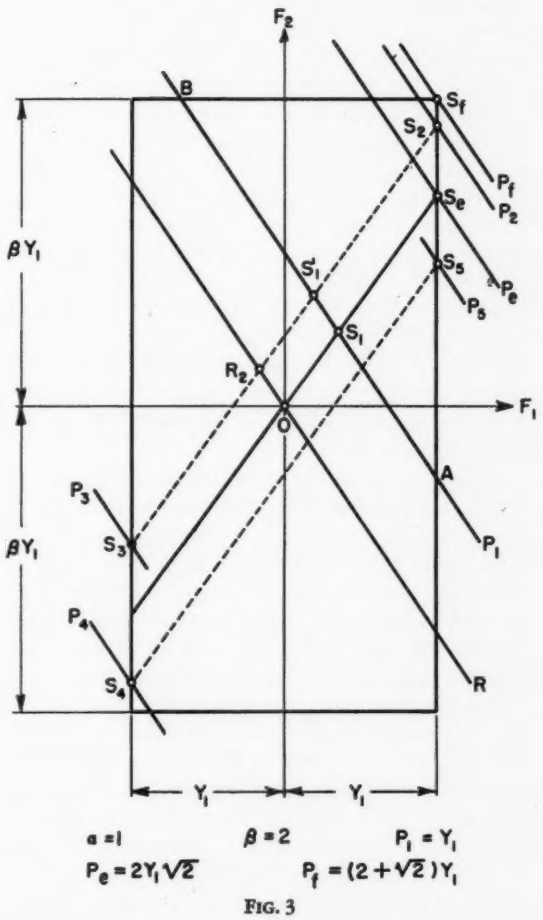


FIG. 3

of the F_1, F_2 plane increases in proportion with the load P.

Let us now assume that, starting from the virgin state, we subject the structure to a load P which is first increased from zero to some value $P_2 > P_e$ and then reduced to zero. Initially, the stress point coincides with the origin O. As the load is increased, the stress point travels along the line of elastic states until it reaches the boundary of the yield rectangle at S_e. Since this point lies on the side $F_1 = Y_1$ of the yield rectangle, the bars OA and OC will now yield in tension. During this yielding, the force F_1 in each of these bars retains the value Y_1, i.e., the stress point will now travel along the line $F_1 = Y_1$. When the load reaches the value P_2, the stress point is at the intersection S_2 of the line of equilibrium for the load P_2 with the line $F_1 = Y_1$. During the subsequent unloading, the structure responds elastically to the decrease in load. Thus, the stress point will move from S_2 towards the interior of the yield rectangle along a parallel to the line of elastic states. For example, when the load has been reduced to the value P_1, the stress point will assume the position marked S'_1 in Fig. 3. For the load P_1 we therefore have the stress point S_1 during the loading process and the stress point S'_1 during the unloading process. This illustrates the fact that in elastic-plastic structures the instantaneous state of stress depends not only on the instantaneous load, but also on the history of loading.

As the load is further reduced, the stress point continues to travel along $S_2S'_1$. For $P = 0$, in particular, we have the residual state of stress represented by the point R_2 on the line of equilibrium through the origin. This line may be called the "line of residual states."

If, instead of unloading the structure after reaching the load P_2, we continue to increase the load, the elastic limit of the bar OB will be reached when the stress point coincides with the vertex S_f of the yield rectangle; the corresponding value of the load will be denoted by P_f, the subscript f standing for "flow." As long as only the bars OA and OB were yielding, the fact that the bar OB was still stressed within its elastic range restricted the magnitude of the permanent elongations in the bars OA and OC. [See Eq (5).] Once the bar OB is also ready to flow plastically, however, there is nothing which prevents the occurrence of large permanent elongations in all three bars. Thus, the load P_f represents the "flow limit" at which the structure becomes useless.

Figure 3 suggests a practically important characterization of the flow load P_f. The points on the boundary of the yield rectangle and in its interior represent states of stress in which no bar is stressed beyond its yield limits in tension or compression. Let us call such states of stress "admissible." For a given load P_1, consider the segment AB of the line of equilibrium which is in the yield rectangle. The points of this segment represent admissible states of stress which satisfy the equation of equilibrium (3) for $P = P_1$. Let us call these states of stress "statically admissible states of stress for the load P_1." Figure 2 shows then that the flow load P_f is the largest load for which a statically admissible state of stress can be found.

This principle can be used as follows to find the flow load P_f. Solving the equation of equilibrium (3) with respect to F_2 and substituting the result into (8), we obtain

$$-Y_1 \leqq F_1 \leqq Y_1,$$

$$-\beta Y_1 \leqq P - F_1\sqrt{2} \leqq \beta Y_2.$$

Multiplying the first of these continued inequalities by $\sqrt{2}$ and adding the result to the second continued inequality, we obtain

$$-(\beta+\sqrt{2})Y_1 \leqq P \leqq (\beta+\sqrt{2})Y_1. \qquad (9)$$

This shows that the largest value of P for which the equation of equilibrium (3) as well as the yield inequalities (8) can be fulfilled, i.e., the largest load for which there exists a statically admissible state of stress, is

$$P_f = (\beta+\sqrt{2})Y_1. \qquad (10)$$

For $\alpha = 1$, $\beta = 2$, the flow limit (10) exceeds the elastic limit (7) by slightly more than 20 per cent. Whereas elastic design is based on the load P_e, "limit design" is based on the flow load P_f. Those who are in favor of limit design maintain that it is more realistic than elastic design. Indeed, in the example just considered, the deformations of the structure remain of the order of magnitude of elastic deformations when the elastic limit is exceeded by nearly 20 per cent. Moreover, limit design using only the equation of equilibrium (3) and the yield inequalities (8) is statically determinate, whereas elastic design must deal with an indeterminate structure. For complex structures, this means that limit design is considerably simpler than elastic design. As a consequence, of this, limit design for minimum material consumption is feasible, whereas elastic design for minimum material consumption proves extremely difficult.

So far, we have considered only positive values of P. To explain another design principle, let us now admit negative values of P but assume that the bars of the structure are prevented from buckling. Admittedly, this assumption would hardly be realistic in the case of a real structure of the type shown in Fig. 1. However, we are using this structure here only as a simple model exhibiting typical features of the mechanical behavior of structures beyond the elastic limit; we are therefore free to introduce simplifying assumptions such as the one ruling out the buckling of the bars of the structure.

Let us suppose that the structure has been loaded in tension up to $P=P_2$, and then completely unloaded so that the stress point is R_2 in Fig. 3. If now the structure is loaded in compression ($P<O$), the stress point moves along R_2S_3 until it reaches the boundary of the yield rectangle at S_3 when the line of equilibrium has the position marked P_3 in Fig. 3. Further loading in compression causes the bars OA and OC to flow under the constant load $F_1=-Y_1$, and the stress point travels along the side $F_1=-Y_1$ of the yield rectangle. Let us now assume that the load P is kept oscillating between given extreme values P_{max} and P_{min}. If the lines marked P_2 and P_4 in Fig. 3 are the lines of equilibrium for these extreme values of the load, the stress point describes the parallelogram $S_2S_3S_4S_5$ during each cycle of loading (except for the first loading from the virgin state to P_2). While the stress point travels from S_5 to S_2, the bars OA and OC yield in tension, and while the stress point travels from S_3 to S_4, these bars yield in compression. Thus, plastic deformations occur during each loading cycle. Experience shows that most materials cannot withstand a great number of repetitions of yielding in tension followed by an equal amount of yielding in compression. Thus, the extreme loads P_2 and P_4 cannot be considered as safe.

On the other hand, if the extreme loads are assumed to be P_2 and P_3, then the stress point will travel along the straight line S_2S_3 from S_2 to S_3 and back to S_2 during each loading cycle. This means that the bars OA and OC yield in tension only during the first loading from the virgin state to P_2; thereafter the bars undergo only elastic changes of length during each loading cycle. To indicate this type of behavior we shall use the expression "the structure shakes down under the extreme loads P_2 and P_3." Under the extreme loads P_2 and P_4, on the other hand, shakedown does not occur.

The following is a typical problem of shake-down design: given the ratio $\rho=P_{min}/P_{max}$, determine the greatest possible value of P_{max} if cycles of plastic deformation are to be avoided. This problem can be treated in a manner similar to that used above for finding P_f. After shakedown has occurred, the actual states of stress under the extreme loads are obtained by superposition of the elastic states of stress corresponding to these extreme loads and a residual state of stress (represented by R_2 in the case illustrated by Fig. 3). This residual state of stress is of the type

$$F_1=R, \quad F_2=-R\sqrt{2}, \tag{11}$$

where the value of R remains to be determined. Indeed, the forces (11) satisfy the equation of equilibrium (3) for $P=0$. The elastic response of the structure to the extreme loads P_{max} and $P_{min}=\rho P_{max}$ is given by (6). The conditions (8) then furnish

$$\left.\begin{aligned} -Y_1 &\leqq R+\frac{\alpha P_{max}}{(1+\alpha)\sqrt{2}} \leqq Y_1 \\ -Y_1 &\leqq R+\frac{\alpha\rho P_{max}}{(1+\alpha)\sqrt{2}} \leqq Y_1 \\ -\beta Y_1 &\leqq -R\sqrt{2}+\frac{P_{max}}{1+\alpha} \leqq \beta Y_1 \\ -\beta Y_1 &\leqq -R\sqrt{2}+\frac{\rho P_{max}}{1+\alpha} \leqq \beta Y_1 \end{aligned}\right\}. \tag{12}$$

To show how this system of continued inequalities is handled, let us consider the case $\alpha=1$, $\beta=2$, $\rho=-3/4$. The first continued inequality (12) is then equivalent to the following two inequalities,

$$\left.\begin{aligned} R\sqrt{2}+\frac{1}{2}P_{max} &\leqq Y_1\sqrt{2} \\ -R\sqrt{2}-\frac{1}{2}P_{max} &\leqq Y_1\sqrt{2} \end{aligned}\right\}. \tag{13}$$

Similarly, the other continued inequalities (12) are equivalent to

$$\left.\begin{aligned} R\sqrt{2}-\frac{3}{8}P_{max} &\leqq Y_1\sqrt{2} \\ -R\sqrt{2}+\frac{3}{8}P_{max} &\leqq Y_1\sqrt{2} \end{aligned}\right\}, \tag{14}$$

$$\left.\begin{aligned} -R\sqrt{2}+\frac{1}{2}P_{max} &\leqq 2Y_1 \\ R\sqrt{2}-\frac{1}{2}P_{max} &\leqq 2Y_1 \end{aligned}\right\}, \tag{15}$$

$$\left.\begin{aligned} -R\sqrt{2}-\frac{3}{8}P_{max} &\leqq 2Y_1 \\ R\sqrt{2}+\frac{3}{8}P_{max} &\leqq 2Y_1 \end{aligned}\right\}. \qquad (16)$$

To obtain an inequality which is free from R, we may add any one containing the term $R\sqrt{2}$ to one with the term $-R\sqrt{2}$. From all inequalities which can be obtained in this manner, we must pick the one which furnishes the smallest value for P_{max}. Thus,

$$P_{max}=\frac{16}{7}Y_1\sqrt{2}. \qquad (17)$$

As is to be expected, this value lies between P_e and P_f.

As this example shows, shake-down design is considerably more complicated than limit design; in particular, the response of the indeterminate elastic structure to the considered loads must be known before shake-down design can be undertaken. As a consequence of this, shake-down design for minimum material consumption proves as difficult as elastic design for minimum material consumption. On the other hand, the load (17) exceeds the elastic limit (7) by about 14 per cent. When reduction of weight is essential, for instance in airplane structures, such a gain in the admissible load may well be worth the additional effort demanded by a shake-down analysis.

Note: **Dr. Prager, who is chairman of the Graduate Division of Applied Mathematics at Brown University, lectured as Walker-Ames Professor at the University of Washington, April 26 to May 20, 1950, on "The extremum principles of the mathematical theory of elasticity and their use in stress analysis." The foregoing paper was presented as a special lecture during Dr. Prager's stay.**

Research Corporation and University Sign Agreement

IN NOVEMBER, 1950, the University Research Foundation concluded its agreement with the Research Corporation of New York, which, through its management of a number of valuable patents, has supplied significant funds to sponsor research in science and technology carried on in schools all over the United States. The Research Corporation was started by Dr. F. A. Cottrell in 1912, and from the income accumulated by his inventions in the electrical field other work in technology was subsidized and other inventions were developed. Since that time the Research Corporation has increased its reserves substantially out of income derived from patents. The Corporation is a non-profit organization; its income reverts to the individuals and institutions that develop useful inventions, and its surplus is contributed in the form of grants-in-aid to workers in research.

The University of Washington Research Foundation was set up in 1942 and was incorporated under the laws of the state. Although now in a formal relationship with the New York organization, the Foundation will manage the allocation of grants-in-aid to its own faculty and students, determine the patentability and usefulness of technical developments submitted for its consideration, and negotiate policy agreements with the Research Corporation.

Inventions useful to industry, having commercial value in excess of their own cost of development, are the seeds of perpetuation for the Research Corporation. The November agreement, therefore, provides that the University Foundation will require an inventor to assign his invention to the Research Corporation. The inventor and the University Foundation will receive valuable consideration for this assignment. The Research Corporation uses its resources and skilled counsel to obtain a patent and to negotiate a licensing contract for the industrial or commercial use of the new development. The inventor receives a fixed percentage of the gross return from his invention, not to exceed 15 per cent, and the University Foundation shares the net return with the Research Corporation on a negotiated basis. Both organizations then use the surplus of income from the invention to subsidize research in scientific and technological fields.

The University Foundation has made efforts to accumulate funds for the prosecution of patents and for the special studies needed before the patent application can be presented. It has used gifts or funds from special sources, when necessary, to advance sound and patentable projects, but it is not designed to make money and functions only as a spokesman and agent for the University worker whose research leads him to a new device or process.

The Research Corporation has stated, in reviewing some of its achievements, that many of its projects have been important both as practical inventions and as advancements in science. The list of such projects includes, for example, the Cyclotron; the Van de Graaf high-voltage generator and X-ray equipment;

utilization of solar energy; computing machines; the synthesis of vitamin B_1; and pantothenic acid.

Here at the University, scores of ideas have been examined: an improvement for athletic equipment, a plan for simplified spelling, a process to obtain commercial alcohol from waste sulfite liquors, and cork from Douglas fir bark. However, it must be pointed out that most of the patentable ideas evolved each year would fail to earn their patent costs, much less return any profits to their inventors. Even "successful" patents rarely return more than nominal sums, and only rarely are earnings of spectacular size.

In accordance with the purpose of its charter, the Research Corporation extended financial assistance to four members of the faculty of the University of Washington during the year 1949. Paul C. Cross, Professor of Chemistry and Executive Officer of the Department of Chemistry and Chemical Engineering, received a grant-in-aid for his work on "Molecular structure, the nature of chemical bonding and molecular interactions"; S. H. Neddermeyer, Associate Professor of Physics, for research on "Ultrafast counters and measuring ultra-short intervals"; W. M. Schubert, Assistant Professor of Chemistry, for work on "Action of magnesium on 1,2- and 1,4-dihalides and haloethers"; and B. S. Rabinovitch, Assistant Professor of Chemistry, for his "Study of the mechanism of fluorination of aliphatic hydrocarbons."

The grants-in-aid supplied by the Research Corporation generally amount to twenty-five hundred dollars for one year. The grants are drawn from funds made available annually for that purpose by the directors of the Research Corporation and are dependent in amount from year to year upon the Corporation's net earnings for each year. The grants-in-aid are intended to promote fundamental research and are made to institutions on the basis of applications by the institutions or on behalf of institutions by the staff members for the support of specific projects.

Another kind of grant that has been made by the Research Corporation is the grant awarded to outstanding teachers chosen on the basis of their proven ability, and given as a direct subsidy for one year.

In addition to their grants-in-aid to the physical sciences, the Research Corporation has a fund which serves the field of medicine. In March, 1940, the Williams-Watterman Fund for the Combat of Dietary Diseases was created. The Fund had its origin in an agreement of October, 1935, whereby the inventors of certain processes for the production of vitamin B_1 and its intermediates assigned their present and prospective inventions in this field to the Research Corporation.

Out of the Williams-Watterman Fund have come the aids to research which have developed the now almost universal practice of enriching white bread and flour. The language of the agreement has been liberally construed to include within the field of the Fund studies in nutrition and metabolism, with the conviction that the advancement of fundamental knowledge in all sciences underlying our use of food is important for the combat of dietary diseases.

Among the institutions signed up with the Research Corporation are the leading universities and institutes in research, and their number is being constantly augmented.

At present the Research Corporation is considering five suggestions for patent submitted by the University of Washington Research Foundation.

CITY AUTHORIZES STUDY OF ATMOSPHERIC POLLUTION IN SEATTLE AREA

Arrangements have just been completed with the City of Seattle which will involve the University in an atmospheric pollution study covering a period of twelve months. Final plans have grown out of conversations with Mr. Ralph Finke, City Engineer, which have been in progress since last June.

The work will be under the supervision of the Environmental Research Committee and under the direction of Mr. A. W. Green, Public Health Engineer in the Division of Public Health and Preventive Medicine at the University. The Engineering Experiment Station will provide certain graduate fellows who will work in the field and laboratory, and the Department of Meteorology will also cooperate.

A portion of the work in this field was accomplished during 1950 in connection with a Master's thesis in Civil Engineering under the direction of Professor Tyler. The study was limited to the trough of the Lake Washington canal and covered only six months of the year.

In initiating this study, the city wishes to ascertain the present level of atmospheric pollution in the Seattle area in order to determine the need for protective legislation.

Dr. Oscar E. Schotte, professor of biology at Amherst College, has invented a process for injecting slaughtered cattle with a fat compound that can change a leathery steer into tasty beef. The compound is forced into the animal's heart under pressure immediately after slaughter and spreads through the tissues, leaving fatty deposits. The Institute of Inventive Research at San Antonio, Texas, is commercially developing the process which will reduce the cost of fattening cattle.

EVALUATION OF EARTHQUAKE HAZARD TO FOUNDATIONS

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R. G. Hennes

An earthquake such as the one that shook western Washington in April 1949 always serves to agitate the engineers and architects of the tremulous region into a review of current design practice. Evidence of increased seismic activity quite properly calls for modification of design standards to meet the increased risk. The conventional engineering response to the earthquake threat is logical and practical, according to the following line of thought: The natural period of vibration of the ordinary structure is likely to be much greater than the usual period of vibration observed in earthquakes. Under such circumstances the structure moves like a rigid extension of the earth on which it is founded. Because in any event the building would have been designed to sustain the vertical pull of gravity, the only additional requirement imposed by earthquake hazard is that the structure be designed to resist a horizontal load proportional to the greatest horizontal acceleration apt to be recorded in a local earthquake.

It would be rash to question the propriety of accepted engineering practice in earthquake design, but there is still much to be said regarding secondary factors that engineers may well take into account. Certainly the designer should be alert for unusually tall structures whose natural frequency is within the range of possible earthquake vibrations. In such cases the amplitude of the vibrating structure may far exceed the amplitude of the earth tremor which excited it. That particular structural problem is not within the scope of the present article, but it is pertinent to this discussion to consider the analogous case presented by a soft saturated soil deposit overlying ledge rock. Given a sufficiently low resonant frequency for the soft stratum, a prolonged vibration of the underlying rock can pump enough energy into the overburden to produce movement of much greater amplitude and acceleration.

If the soft saturated soil is also noncohesive, as a loose fine sand, even more spectacular effects can result. Such soil is compacted by vibration, and during the transition into a denser state the supporting power of the soil is greatly impaired. Under these conditions a building founded upon such soil might suffer severe damage which was inaugurated before any member of the structure was set in vibration. Design for horizontal acceleration is quite irrelevant under these circumstances. The building fails not because it is overloaded, but because of the withdrawal of its support. This danger is not remote on the sediments of Western Washington, where in a number of localities underlying sand was flushed to the surface through crevices during the 1949 earthquake.

K. H. Chang

The above considerations suggest that for a given seismic disturbance structural damage is likely to increase with higher values of the natural period of vibration of soil upon which the building is founded, other things being equal. As a matter of fact it is common observation that the most severe damage is found in sections of a city built upon such soils.

Finally, it must be remembered that no damage would ensue if all the energy released by a quake were lost in the internal friction of the overlying soil layers. Thus the nature of the soil affects earthquake hazard through its damping properties.

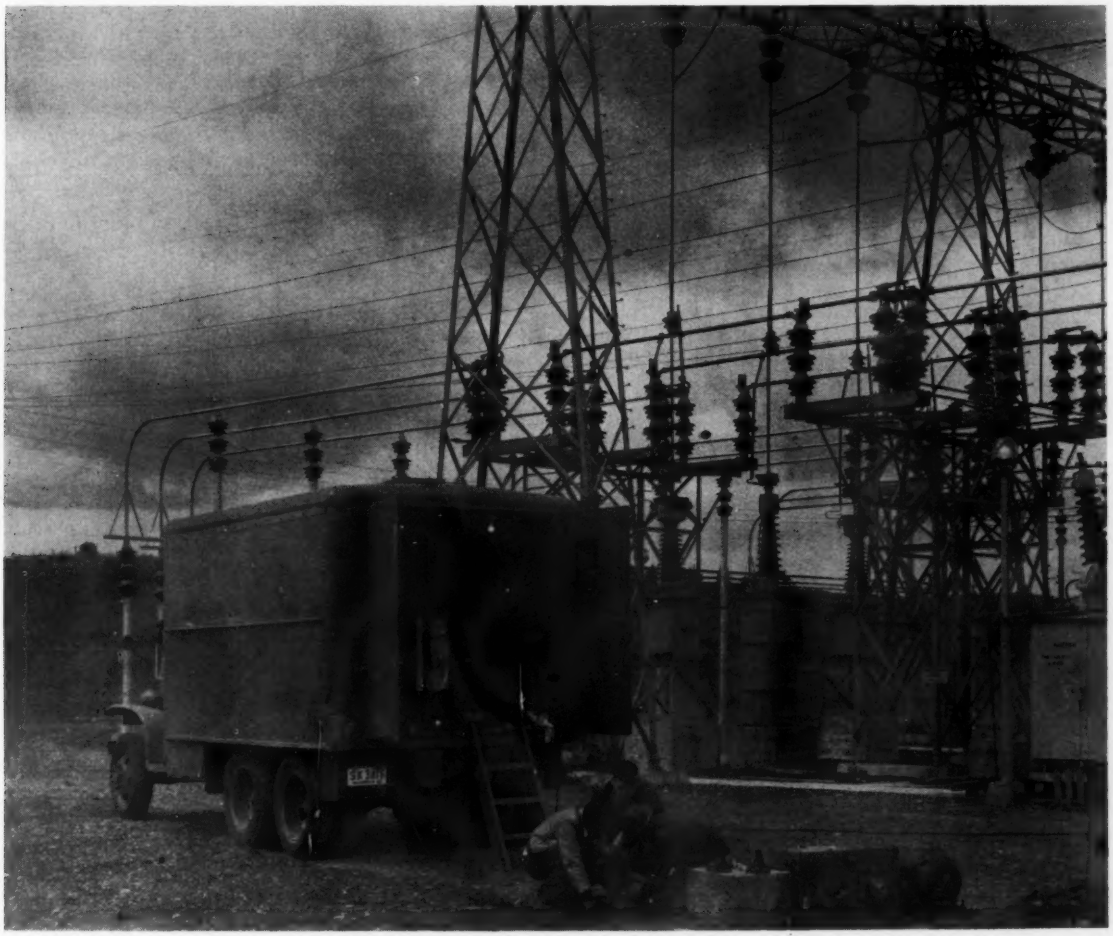
The resonant frequency and the damping coefficient of foundation soils have a direct bearing on the hazard introduced by earthquakes.

Among the agencies faced with responsibility for obtaining adequate structural security in the face of increasing seismic activity, was the Bonneville Power Administration. Engineering Experiment Station Project 81 was organized in answer to their request for an investigation of the earthquake hazard at various important substation sites. Work on the project has been in progress throughout 1950.

The initial phase of the study was devoted to the design of a suitable mechanical vibrator, which could be taken into the field for the determination of dy-

namic soil properties *in situ*. The vibrator should be as large as practicable, so that the results would be influenced to the greatest possible extent by subsoil rather than topsoil conditions, and so that earth wave characteristics could be picked up at reasonable distances from the source, without too much difficulty in instrumentation. The value of 2½ tons was selected for the vibrator plus its base. This decision also fixed the maximum unbalanced force to be exerted by the machine, which could not exceed the weight of the machine without lifting it from the ground on each reversal of direction. It was found that the vibrator as built could be driven by a five-horsepower motor. The motor-vibrator assembly weighed 1,500 lb, and was rigidly attached to a sectional reinforced concrete base weighing 3,500 lb. The bottom of the base was circular, having an area of ten square feet. The machine was thus intermediate in size between previous ½-horsepower American vibrators and a fifteen-horsepower vibrator developed in Germany before the war. The equipment set up at Snohomish is shown in the photograph on the cover.

The vibrator consisted of two parallel horizontal shafts revolving in opposite directions. On each shaft were mounted two eccentric weights, one fixed and the other adjustable. When the movable weight was placed directly opposite the fixed weight the shaft was in balance. When the two weights were in adjacent positions the maximum centrifugal force was exerted, for any specific rate of rotation. The machine was designed to operate at shaft speeds of 10 to 50 revolutions per second. The motor ran at 1,750 rpm, and the vibrator frequency was varied by using different combinations of pulleys in the V-belt drive. In any specific series of test runs the centrifugal force



SETTING UP VIBRATOR AT COVINGTON

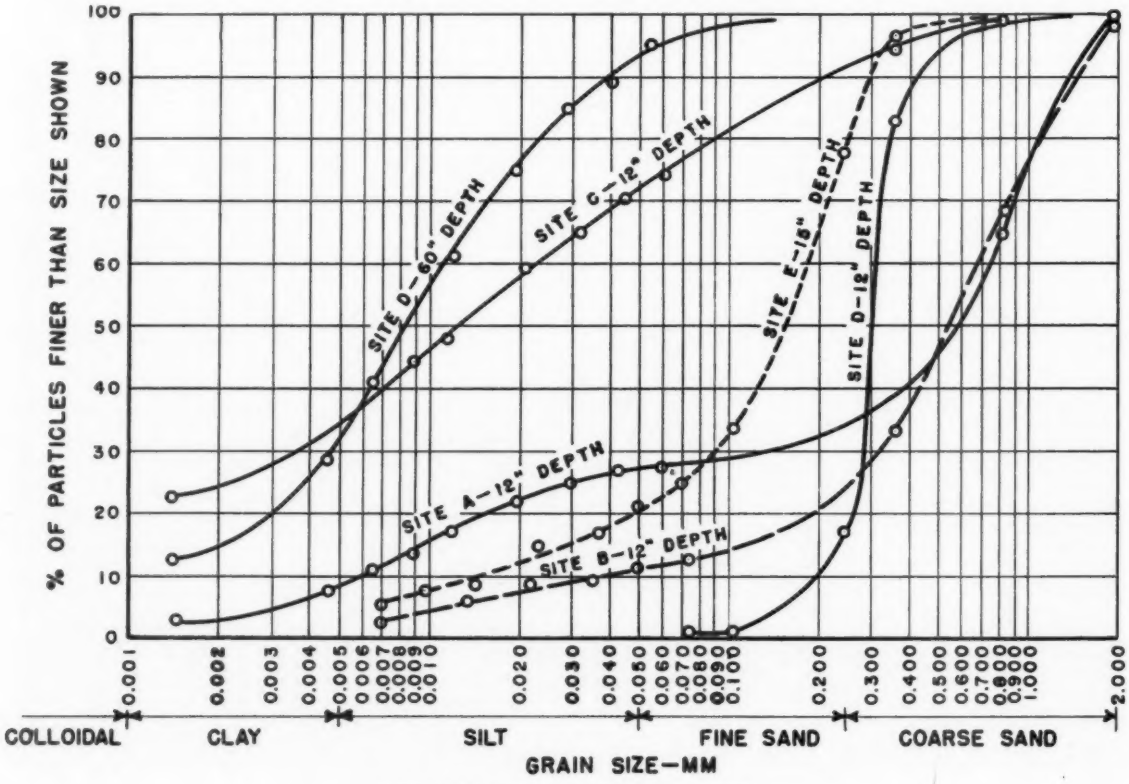
was kept constant at varying frequencies by making a compensating adjustment of the vibrator shaft eccentricity for each run.

Because of the small amplitude of the earth vibration, measurements had to be made electrically. Two electromagnetic pickups were used. A cathode-ray oscillograph connected with the amplifier showed the wave form of the vibration. Signals were fed to a two-channel brush-recorder, where the phase relations between them could be determined. The recorder also received signals from a tachometer on the rotating shaft of the vibrator.

Calibration of the instruments was a major job, which was somewhat simplified by use of a laboratory shaking table providing vibrations of known frequency and amplitude. The magnitude of the signal was found to vary linearly with the amplitude of the vibration at a given frequency, for frequencies above 15 cycles per second.

All mechanical and electric equipment is transported in a four-wheel drive medium truck, equipped with a half-ton capacity crane and hoist. At the test site a 43-in. diameter hole is first excavated to a depth of 18 in. It was found that more consistent data were obtained after a 36-in. diameter steel ring, 6 by 0.125 in. in cross section, was buried flush with the bottom of the excavation. Without the ring a troublesome rocking action sometimes developed during operation of the vibrator. The concrete base is then assembled in the hole, and the vibrator unit bolted in place. Excess excavation is filled with well-tamped soil. The eccentrics are then adjusted to provide the desired centrifugal force, which was standardized at 1,000 lb. A number of extra runs were made with forces of 500, 1,500, and 2,000 lb to obtain supplementary information. During each run the galvanometer and wattmeter are read and the brush recorder switched on briefly. The machine is then stopped, and the belts changed to provide the frequency required for the next test run. Observations are made at 16 frequencies ranging from 7½ to 50 cycles per second. Through the calibration curves previously mentioned it is possible to translate the instrumental data into the actual amplitude of the vibration at the location of the pickup. The amplitude of the vibration reached its maximum value at resonant frequency.

Wave length of surface waves were determined at



GRAIN-SIZE DISTRIBUTION FOR FIVE SITES

TABLE I

SUMMARY OF DATA

Site	Natural Frequency (cps)	Velocity of Surface Wave (fps)	Relative Damping
A	34	1030	0.157
B	32	740	.....
C	39	932	0.214
D	20	536	0.218
E	32	670	0.252

resonant frequency by moving the ground pickups until they were half a wave length apart. This condition could be recognized by arranging that one of the pickups gave a horizontal signal, and the other a vertical signal on the oscillograph. When the two pickups are in phase, the Lissajou's figure becomes a straight line. When this condition is fulfilled, two points on the earth surface are experiencing vibrations with a phase difference of an integral number of half wave lengths. These points are located on the ground with respect to a fixed point of reference. It is of interest to note that if the signals from the two points are of the same magnitude then the straight line (Lissajou's figure) will have an inclination of 45°. The strengths of the signals are determined from readings of the galvanometer as well as from the brush-recorder. Repetition of this process serves to explore variations in wave length and amplitude with distance from the vibrator; these data are needed for determination of the damping coefficient of the soil.

So far field studies have been made at important substations in Washington, and the investigation may be extended to cover several sites in Oregon. The nature of the data may be pretty well inferred from the accompanying graphs and tables. In Table I the inferiority of foundation conditions at Site D is evident. Both the low natural frequency and the low wave velocity are indicative of lower bearing capacity and higher settlement under dynamic action.

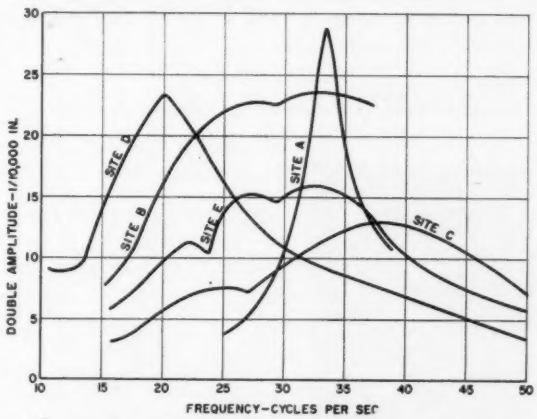
Probably because of the high water table as shown in Table II the relative damping is not notably out of line with the other sites. It is noteworthy that the structures at Site D experienced more severe damage than the other installations during the 1949 earthquake.

The project has been notably successful in determining resonant frequencies at every site, thus providing engineers for the first time with a quantitative measure of earthquake hazard to foundations and an important clue to the relative magnitude of the horizontal acceleration to be expected at competing locations. Moreover there is some reason to hope that new basic information may be forthcoming from the investigation.

TABLE II

DATA FROM LOG OF BORING

Site	Depth	Soil Description
A	0 – 80′	Glacial till
	80 –150′	Sand and gravel with a few clay strata
		Water table at 73′ depth
B	0 –100′	Gravel with sand and some clay in voids
		Water table at 10′ depth
C	0 –500′	Clay with a few sand and gravel layers
		Water table at 124′ depth
D	0 – 4′	Sand fill
	4′– 70′	Silt
	70′–180′	Clay
	180′–220′	Fine sand
	220′–248′	Gravel and sand
	248′–	Ledge rock
		Water table at 6′–2″ depth



AMPLITUDE VS. FREQUENCY CURVES FOR FIVE VIBRATION TESTS IN WASHINGTON

The authors wish to acknowledge substantial contributions to the development of the apparatus made by Mr. Harold Mason and Mr. Horton Dennis, formerly research fellows in the Engineering Experiment Station. For electrical instrumentation, Project 81 has been dependent upon the abilities and cooperation of the Engineering Experiment Station specialists in electronics, Mr. Andrew Jacobsen and Mr. LeRoy Barter. Professor J. B. Morrison of the Mechanical Engineering Department contributed valuable suggestions toward the design of mechanical vibrator details.

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COVINGTON SOIL STRUCTURE

PRELIMINARY STUDY OF THE RECOVERY OF ALUMINA FROM OREGON LATERITES*

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J. S. Chittenden

Introduction

A large deposit of laterite, containing high percentages of alumina and iron is located in Oregon between Rainier and Hillsboro, in addition to two smaller deposits near Salem.[1] Because of the proximity of these deposits to the large alumina reduction works on the Columbia River, the deposits aroused considerable interest.[2] The problem was to develop a process for the economic treatment of the material.

The deposits contain substantially the same percentage of alumina and ferric oxide. For this reason, the Bayer process, commonly used on bauxites of high alumina content, was unsuitable. For economic treatment of the Oregon laterite, it appeared desirable to employ a process that would recover the iron as well as the alumina. The Pedersen process,[3] used for some time by European companies,[4, 5, 6, 7] met this requirement. The project discussed in this article was undertaken as a study of the variables of the Pedersen process as applied to the Oregon laterites.

R. W. Moulton

Nature of the Deposits

The laterite deposits occur on flat-topped hills, on ridges and gentle slopes. The deposits form definite strata varying in thickness from a few inches to more than twenty feet. The varieties include a hard pisolitic type, a softer earthy variety with hard porous nodules and angular fragments, and a hard porous granular type. The Alcoa Mining Company reported the following textural varieties and percentages of each as averaged by their drillings: pisolitic, 36 per cent; banded, 5 per cent; nodular, 12 per cent; upper fine grain, 37 per cent; lower fine grain, 10 per cent. This list also indicates the usual order in which the various types are found when drilling from the surface. The composition of the types is not appreciably different, but the tendency is for more iron to appear in the pisolitic or top section than in the lower fine-grain region at the base of the deposit. The lower fine-grain

*Condensed by N. R. Mukherjee, Associate in Chemical Engineering, from the M.S. thesis submitted by J. S. Chittenden, University of Washington, 1948.

deposits found in some areas contain higher concentration of alumina and less iron and more closely approximate a composition similar to bauxite.

The Alcoa Mining Company completed a large drilling program and gave the following average analysis of the samples taken in their drilling operations as of November, 1947: Al_2O_3, 34.20 per cent; Fe_2O_3, 33.99 per cent; SiO_2, 6.62 per cent; TiO_2, 6.43 per cent; loss on ignition, 18.77 per cent.

Pedersen Process

Bauxite (or any other suitable aluminum ore), limestone, and coke are charged into the electric furnace where the smelting occurs. The iron in the raw materials is liberated in the molten state exactly as in the electric blast furnace. If iron ore is added when siliceous aluminum ore is being worked, the bulk of the silica can be combined with the iron to make ferrosilicon. The iron by-products are stated as being readily marketed at favorable prices. The aluminum is generally held in the slag by the formation of the aluminate, which makes it possible to effect a fairly complete separation of aluminum and iron. In closed type furnaces, the process gases of approximate heating value of 200 Btu per cu ft can be utilized. The calcium aluminate slag is ground and extracted with soda and then thickened to yield an aluminate lye and a slurry. The lye is neutralized with carbon dioxide to precipitate alumina, which is then filtered off. The residue of the filtration, hydrated alumina, is calcined with furnace gas to yield the final product, which can be used as a raw material for the manufacture of aluminum by the Hall process. From the calciners, the waste gases, largely carbon dioxide, pass through an electrostatic cleaner and are recycled to the precipitator.

The important control problem in the operation of the Pedersen process is to produce the soluble monocalcium aluminate, because dicalcium aluminate is insoluble in alkali. A proposed equation[8] for the reaction between monocalcium aluminate and the extracting solution is as follows:

$$\underset{\text{(slag)}}{5CaO \cdot 3Al_2O_3} + \underset{\text{(extracting solution)}}{3Na_2CO_3 + 2NaHCO_3} = \underset{\text{(extracted product)}}{6NaAlO_3} + 2NaOH + \underset{\text{(residue)}}{5CaCO_3}$$

The initial mixture must be closely proportioned to produce monocalcium aluminate. This range has been found to correspond partly with the range which may be used in producing rapid-settling cements.[9]

Of the four elements present in laterite, iron is most easily reduced, followed by silicon, aluminum, and titanium, in that order. Side reactions affect the reduction of the last three elements. If ferrous oxide, FeO, is present in the slag, silicon is oxidized back to silica and is retained in the slag. If small amounts of silica are present, the basic nature of the slag makes re-entry into the metal, by reduction of the silica, difficult.[6, 10, 11] Titanium, though being the most difficult of the four elements to reduce, in the presence of iron forms ferrotitanium, which settles to the bottom of the furnace. This reaction[12] proceeds most rapidly at high temperatures (1800° C).

Experimental Work

Preliminary work was conducted in the laboratory to develop a familiarity with the technique required in operating the Pedersen process with Oregon laterites. Numerous runs were made at 1500° C using a resistance-type furnace and later with a 25-kva arc furnace. Following the preliminary work, six variables were selected for possible study:

1. *The optimum ratio of carbon to laterite in the charge.* It is desirable that the ferric oxide be completely reduced to metallic iron, while alumina remains unreduced in the slag. Whether the iron or slag contains the majority of the titania and silica is also dependent on the reducing action of the carbon.
2. *The effect of limestone on the amount of alumina recovered.*
3. *The amount of iron ore added to the charge.* The addition of iron to the furnace charge affects the location of the silica in the product.
4. *The temperature to which it is necessary to heat the charge.* This variable is important to the economics of the Pedersen process.
5. *The duration of the run.* This variable is also closely tied to the economics of the Pedersen process.
6. *The optimum conditions for the extraction of the alumina from the slag and the number of extractions necessary for complete recovery of alumina on an economic basis.*

The experimental equipment available for the work limited the extent to which these variables could be studied. The 25-kva furnace, the cross section of which is shown in Fig. 1, was not designed for this process and was too small to permit an accurate economic analysis of the process. The temperature and duration of the run were two variables that could not be studied.

In the operation of this furnace the upper electrode is lowered until it touches the bottom of the crucible. The charge is then added, the current turned on, and the upper electrode then raised until a steady arc allowing about 400 amperes to flow is obtained. To avoid crumbling of the graphite crucible due to overheating, water was added to the magnesite refractory to cool the outside crucible walls. This was largely done in order that two runs could be conducted in

the same crucible. After two runs, the bottom of the crucible was completely burned away, and a new crucible was needed.

Since maximum skill was necessary to maintain a steady arc, no attempt could be made to control the temperature. The fused mass cooled and solidified in regions not adjacent to the arc. The solid mass presented a barrier keeping the unfused material from the high-temperature region, and made it difficult to obtain complete fusion of the charge. The temperature and duration of the runs were held as constant as possible to decrease the effect of these variables on the result during the investigation of the other variables. Each run was continued for one hour after the major portion of the charge appeared to be completely fused.

Seven runs were conducted in the 25-kva furnace. The amount of laterite was kept constant throughout and one variable was studied in each run. The results are given in Table I.

Composition of the Materials Used

The laterite obtained from the Alcoa Mining Company was segregated into the textural types discussed before. These types were mixed in the laboratory in the proportions in which they occur in the deposits to make one material for the experimental work. The analysis of the mix, which was used in all experiments, was as follows: Al_2O, 37.80 per cent; Fe_2O_3, 36.25 per cent; SiO_2, 6.68 per cent; TiO_2, 5.45 per cent; loss on ignition, 13.90 per cent.

The solution used for extraction of the slags obtained in the experimental runs was a 3 per cent Na_2CO_3 solution containing 0.25 per cent NaOH by weight.

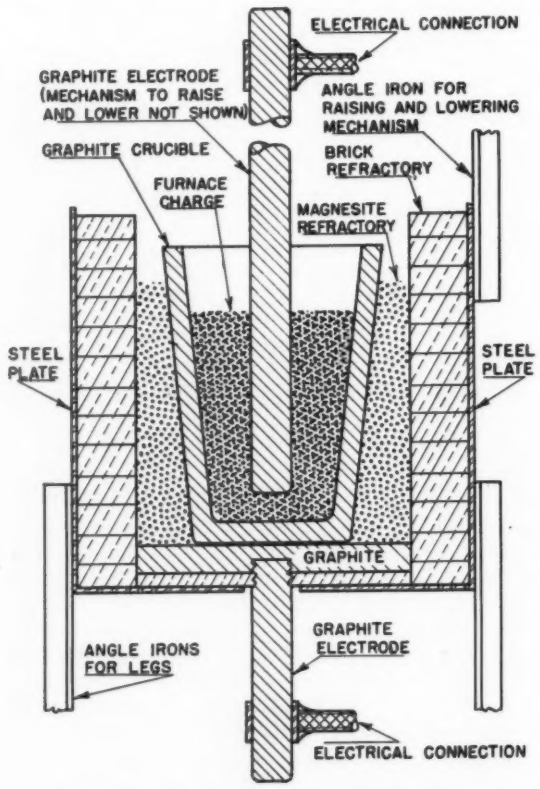

FIG. 1. CROSS-SECTION VIEW OF 25-Kva FURNACE
(Not to scale)

Analytical Work

The general procedures followed for the analysis of Fe, Al, Si, and Ti are outlined in the literature.[13] Particular difficulty was met in attempting to sample the iron alloy obtained. It was necessary to use a carboloy tool and to sample the surface layers.

The slags were crushed in a jaw crusher. Aqua regia failed to bring about the complete solution of the slag and alloy material. A method was adopted of treating 0.5-g samples with 5 ml of HF and 2 ml of H_2SO_4 and heating in a platinum crucible. After the acid fumes were expelled, the samples were ignited and were fused with Na_2CO_3 and dissolved in dil. HCl. This method assured the complete solution of the samples. The iron and titanium were determined volumetrically, and the aluminum and silica gravimetrically.[13]

Discussion of the Experimental Work

The equipment available for use in the laboratory was not designed for this study, as has been mentioned. The graphite crucible provided excess carbon so that control of the amount of carbon was not possible. The carbon added to the run as charcoal was of the order of 1.4 lb, but the actual carbon consumed because of electrode and crucible loss was nearly 4 lb. However, industrial furnaces in use in the Pedersen process have refractory walls and, therefore, can be closely regulated for carbon or coke consumption.

The charge was not uniformly heated since the crucible was too large for the furnace capacity. In each run, a portion of the charge remained unfused. The slag could be classified into two fractions: one, the mass solidified above the alloy puddle, and the other, that which had solidified on the walls of the crucible. The portion taken for analysis was that above the alloy, because this slag was more uniform in appearance and was heated for the longest period of time.

During the first run made in the 25-kva furnace (shown as Run No. 2 in Table I), a large portion of the charge was blown from the crucible as dust by exhausting gases. To avoid this loss of material, the

TABLE I

RUN	1	2	3	4	5	6	7
VARIABLE UNDER STUDY	Optimum	Large Excess Carbon	Excess Carbon	Insufficient Carbon	Excess Limestone	Insufficient Limestone	Additional Fe_2O_3
FEED CHARGED TO FURNACE (lb)							
Laterite	20	8.45	20	20	20	20	20
Limestone	14	5.4	14	14	19	9	14
Carbon	1.4	1.0	2.0	0.7	1.4	1.4	1.4
Fe_2O_3	...	...	...	...	...	...	4.2
Graphite lost by electrode	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Graphite lost by crucible	1	2	1	1	1.25	1.5	1
Actual carbon consumed	3.65	4.25	4.65	2.95	3.9	4.15	3.65
CONDITIONS OF RUN							
Average temperature (°C)	1600	1700	1600	1600	1600	1600	1600
Duration of run (hr)	4	5	7	6.5	5	4.5	5.75
Average current reading (amp)	450	400	400	400	450	450	400
Average voltage reading (v)	45	45	45	45	45	45	45
Electrical energy (kwhr)	64.3	....	111.3	87.8	79.7	71.8	76.0
PRODUCTS OBTAINED (lb)							
Slag	14.62	....	15.25	16.25	17.5	14.5	17.75
Alloy	3.5	....	3.12	2.96	3.14	3.25	3.25
Unfused	0.98	....	1.21	1.05	2.35	0.42	2.78
Unfused lost as dust	0.25	....	0.25	0.25	0.25	0.25	0.25
Total weight	19.35	....	19.83	20.51	23.24	18.42	24.03
ANALYSIS OF SLAG (%)							
Al_2O_3	42.10	39.30	45.20	40.80	40.80	50.70	40.60
FeO	4.72	1.30	6.23	9.83	6.79	4.95	16.23
SiO_2	8.42	9.20	8.30	7.65	6.52	9.08	7.85
TiO_2	3.71	1.00	5.12	3.30	2.92	3.82	4.46
CaO	41.05	49.20	35.15	38.42	42.97	31.45	30.86
C	Trace	Trace	Trace	Trace	Trace	Trace	Trace
ANALYSIS OF ALLOY (%)							
Al	4.3	6.9	5.8	5.0	2.6	2.1	7.6
Fe	93.2	86.9	92.5	87.3	94.5	95.1	89.8
Si	0.1	2.9	0.3	0.7	0.1	0.1	0.0
Ti	2.0	3.4	0.3	2.0	1.9	1.7	0.62
C	Trace	Trace	Trace	Trace	Trace	Trace	Trace
EXTRACTION OF ALUMINA (g) (20 g of slag treated with 200 g extracting solution)							
1st extraction	1.34	0.94	1.50	1.94	0.64	1.95	1.11
2nd extraction	0.36						
3rd extraction	0.11						

charge to the furnace was mixed with enough water to dampen it and hold it together. This addition of water kept the unfused portion at the top of the charge from being blown out of the furnace.

Conclusions

The application of the Pedersen process to the Oregon laterites produces a dense, hard, metallic alloy of iron and a calcium aluminate slag.

A large excess of carbon results in the reduction of alumina and titania to the metallic form. Dusting of one slag was also noted when a large excess of carbon was used. An insufficient amount of carbon resulted in the incomplete reduction of the iron and the presence of a higher percentage of FeO in the slag.

The addition of ferric oxide to the charge of laterite, limestone, and carbon resulted in the incomplete reduction of iron. The presence of high percentages of ferrous oxide in the slag resulted in oxidation of the silicon to silica, keeping it in the slag. No silicon was found in the alloy of this run (Run No. 7).

The extraction of alumina from the slag left much to be desired. There was no apparent reason why such a small percentage of alumina was extractable. The recovery of alumina was approximately only 20 per cent of the alumina in the slag. Each additional stage of extraction recovered less than one-third of the alumina obtained in the previous extraction.

The titania in the laterite on fusion in the furnace is found both in the slag and the iron alloy. The recovery of titania from the residue left after extracting the alumina does not appear economically attractive. The titania in the laterite would not increase the value of the ore in this method of processing.

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Notes and Comments

ENGINEERS IN THE NEWS

H. E. WESSMAN, Dean of the College of Engineering, attended the joint meeting of the Engineering College Administration Council and the Engineering College Research Council held in Washington, D.C., November 16-17. He is a member, appointed by the ECAC, of the joint committee to further cooperation of educational institutions and governmental agencies. Joining him there, and also a member of the same committee, representing the ECRC, was **F. B. FARQUHARSON,** Director of the Experiment Station. Discussed at the meeting were such emergency problems as that of technical manpower, the possible revival of college training programs such as ESMWT, research personnel in colleges, and the encouragement of basic research which was largely abandoned during World War II. Dean Wessman also conferred in Washington with Dr. Hugh L. Dryden, Director of the National Advisory Committee for Aeronautics, regarding proposed allocation of funds under the Unitary Wind Tunnel Plan of 1949. While in the East, Professor Farquharson and **G. S. VINCENT**, Principal Bridge Engineer of the Bureau of Public Roads, who have been engaged in research on suspension bridges, attended the annual meeting of the Advisory Board on the Investigation of Suspension Bridges held in New York, November 14-15, and reported on their work.

Dean Wessman and Professor Farquharson also attended the meeting of the State Pollution Commission at Olympia, December 14, the former as a member of the Air Pollution Committee, and the latter, a member of the Environmental Research Committee, an advisory group from the University. **R. G. TYLER,** Professor of Sanitary Engineering, **L. E. POWERS**, Director of Public Health, and **A. W. GREEN,** Sanitary Engineer in the Division of Public Health, were other members of the Environmental Research Committee present. The meeting was called to consider the question of possible legislation with respect to the air-pollution problem.

G. E. SMITH, Professor of Electrical Engineering, will read a paper on "Factors Useful in Heat Pump Design" before the meeting of the American Society of Heating and Ventilating Engineers in Philadelphia, January 23, and will also attend the convention of AIEE in New York.

R. B. VAN HORN, Executive Officer of the Civil Engineering Department, attended the first meeting of the Hydraulics Division of the ASCE held jointly with the annual meeting of the Mid-South Section at Jackson, Mississippi, November 1-3. A feature of special interest was the inspection trip to the U. S. Waterways Experiment Station.

P. H. CAWLEY has been assigned to an Engineering Experiment Station fellowship in Chemical Engineering sponsored for one year by General Electric (Hanford) to determine the drying characteristics of graphite. He will investigate such factors as temperature, gas-flow rate, humidity, and moisture content.

FOURTH ROAD CONFERENCE TO MEET

The fourth Northwest Conference on Road Building will be held in More Hall, February 14-15-16, 1951. Past meetings have been attended by over three hundred engineers from Washington, and adjoining areas. Speakers of local and national reputation will discuss recent developments in paving materials, prestressed concrete, heavy traffic, subgrade and base treatments, highway operation and finance. Interested engineers and public officials are invited to write for a program. Arrangements are being made to permit preregistrants to reserve tickets for the Idaho basketball game and performances at the campus theatres.

POWER-RATING TESTS OF WORM GEARS*

L. B. COOPER
Assistant Professor of Mechanical Engineering

H. J. SCHWABE
Research Fellow, Engineering Experiment Station

L. H. Cooper
Harvey-Nelson

The literature on the subject of power rating reveals a wide divergence of opinion as to the proper method to use in analysis or design. Many engineers dislike using a worm-gear set because of this uncertainty as to rating and because of the low efficiency as compared with an equivalent spur or helical reducer. Moreover, numerous factors affect the power-transmission capacity of a worm-gear set, such as the materials, the lubricants, the size of the set, the sliding velocity, the extent of tooth contact, and the type of housing enclosing the unit. On the other hand, the first cost of the worm-gear set for a high ratio in a moderate size is so much less than that of the other type that economy may dictate its use. Substantially accurate rating formulas have already been developed by the American Gear Manufacturers Association for the rating of sets manufactured according to a closely defined standard as to material, finish, housing, etc., but it would be a substantial contribution to knowledge on the subject if formulas were developed to include a considerably wider variation in factors affecting the rating. This contribution we expect to make with the test floor we have designed, built and are operating.

The requirements for the test stand are somewhat unusual. The power source should be capable of overloading a fairly sizable gear set at input speeds varying from about 300 rpm to 2,000 rpm. This means a motor of about 50 hp with some method of varying the speed at the reducer input shaft. Some means must be provided for measuring accurately the input power over a wide range of speeds and loads. The device to absorb the power output of the reducer should be capable of measuring accurately this power at output speeds ranging from 30 rpm to 500 rpm and up to a maximum load of about 50 hp. A study of these requirements and a pricing of commercially available torque-mounted driving motors, shaft torsion meters, and absorption dynamometers brought us to the conclusion that to design and construct our own test equipment was the only solution if the job were to be completed on a reasonable budget. Valuable assistance was rendered the project by four Seattle industrial firms, Markey Machinery Company, Pacific Car and Foundry Company, Washington Iron Works, and Western Gear Works, who built sections of the equipment to our design at a considerable reduction from the normal cost. Inasmuch as the torsion meter and absorption dynamometer designs that were worked out are somewhat unusual and might be of as much interest to design and test engineers as the results on gear tests, they will be described in some detail.

H. J. Schwabe

Many shaft torsion meters have been built using electric, magnetic, electric strain gage, optical, and mechanical means for torque measurement. The one designed and built was a mechanical type, an adaptation of the principle used in the Kenerson* torsion meter, using links in tension with attached electric strain gages to measure force rather than a hydraulic capsule as in the original design. Figure 1 is a section view of the central portion of the device. An outboard bearing at each end and shaft extensions to accommodate couplings complete the unit. Since it is difficult to determine the action from this view which is intended to show construction detail, a simplified diagram, Fig. 2, is shown. In the operation of this torsion meter, the axially projecting arms of three right-angle bell cranks pivoted on the periphery of the driven shaft flange are driven by radially projecting rollers on the periphery of the driving shaft flange. Pivoting of the bell cranks is prevented by the tangential arms of the bell cranks which bear on

*Based in part on the thesis submitted by H. J. Schwabe in partial fulfillment of requirements for the degree of M.S. in M.E., 1950. This study, a continuation of work begun by H. M. Tapay (M.S. in M.E., 1949), was carried on as Engineering Experiment Station Project No. 3.

*Moyer, J. A., *Power Plant Testing*, New York, McGraw-Hill Book Co., Inc., 1934.

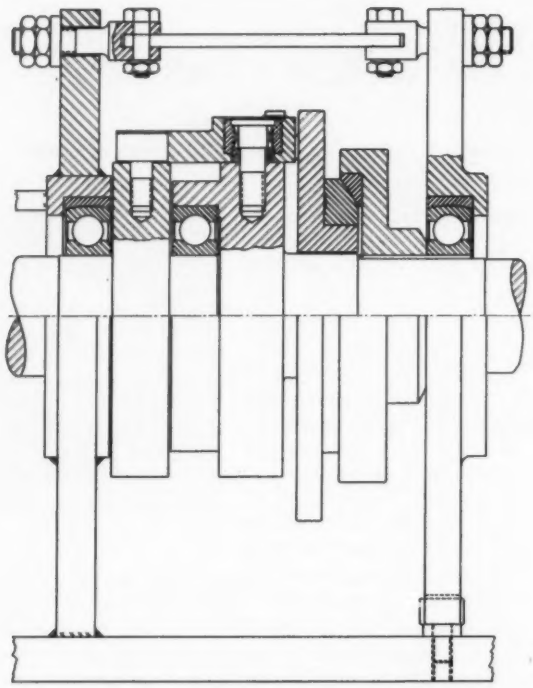


FIG. 1. SECTION VIEW OF TORSION METER

a pressure plate that is restrained from axial movement by three tension links attached to the frame of the instrument. (This restraint is through a spherical seat for equalizing purposes, and a ball bearing in order that the flanges may rotate and the links remain stationary.) The tension in these supporting links is proportional to the tangential driving force on the flanges and therefore is a measure of the torque being transmitted. This torque can be calculated if the radii of the flanges and the lengths of the bell crank arms are known. However, these distances are somewhat indeterminate, and the instrument was calibrated by coupling it directly to the absorption dynamometer.

A friction brake seemed to be the only practical solution to the absorption of 50 hp at low speeds, inasmuch as the commonly used electric and hydraulic dynamometers are high-speed devices. Band brakes, block brakes and rope brakes are uneven in load application and difficult to control and cool. The Alden brake* seemed to overcome these objections, but information about its characteristics and use was meager. Fortunately we learned that the Pacific Car and Foundry Company had designed, built, and used on equipment tests a brake of similar design, using more modern friction materials than in the original

*Moyer, J. A., *loc. cit.*

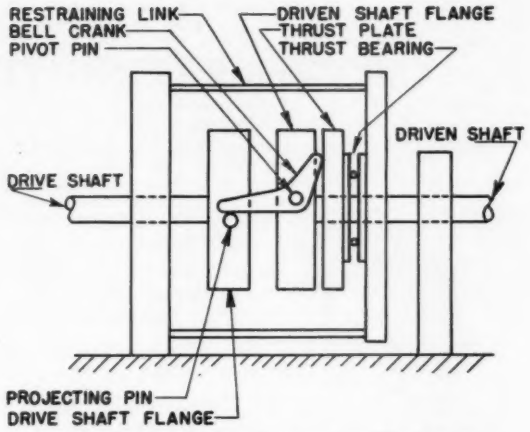


FIG. 2. SIMPLIFIED DIAGRAM OF TORSION METER

model. With their cooperation, we designed and built a brake similar to theirs that has proved very satisfactory.

Figure 3 is a partial section showing the construction of the rotating element and the casing. The complete unit may be seen in Fig. 4. A fabricated steel disc mounted on the dynamometer shaft is faced on both sides with a woven friction material. Two thin and flexible steel discs are adjacent to the rotating central member and are pressed against it by water under pressure in the annular chambers outside the discs. Tendency of the discs and casing to rotate is measured by electric strain gages on a restraining link and is, of course, a measure of the torque on the shaft. This restraining link is in the form of an eyebar of rectangular cross section. A clevis on each end attaches it to a lug on the casing and to the base frame. Hydraulic pressure for loading is supplied by a small gear pump which pumps water from a large reservoir through the brake, through a discharge control valve and back into the reservoir. Load control is by throttling the outlet from the brake so as to build up pressure in the annular chambers.

In the original design the thin, flexible discs were extended and clamped to the casing at both inner and outer edges. "Dishing" of the steel discs upon the application of hydraulic pressure resulted in unit pressures at the center of the contact area that were too high, causing galling or scouring of the brake lining and the discs. This difficulty was overcome by decreasing the size of the discs and bonding neoprene rings to the inner and outer edges, as shown in Fig. 3. The flexibility of the neoprene permits the discs to move in against the central disc without "dishing." It is interesting to note that the bond between the steel and the neoprene is sufficiently strong to transmit the torque from the discs to the housing. The

neoprene was not molded under pressure but bonded by heating.

Mention has been made of the fact that electric strain gages were used to measure the forces on the restraining links. This method has advantages over the use of scales or hydraulic systems when strain indicators are available. The links were made of high tensile strength duralumin with a modulus of about 10,000,000 in order to obtain the greatest amount of strain for a given load. The cross-section areas of these links were chosen so that stresses of 10,000 psi to 40,000 psi exist over the range of loads for which the links are used. The resulting strains vary from 1,000 to 4,000 μin. Experience has indicated that reading variations on the strain indicator are no more than 20 μin., or 2 per cent of the smallest strain. This degree of accuracy is desirable in determining the efficiency of the gear set, since the load at maximum efficiency may be taken as the maximum load that the unit should carry. The necessity of having a high strain and unit stress in the links at low powers or high speeds results in the use of links with a very small cross section. For instance the tangential force at a 3-in. radius required to transmit 5 hp at 1,000 rpm is 105 lb. When the load is distributed over three links, the load per link is 35 lb, the area necessary to result in a stress of 10,000 psi is 0.0035 sq in., and the dimensions are about $\frac{1}{8}$ in. by $\frac{1}{32}$ in. The Baldwin A-12, SR-4 strain gage will work on a $\frac{1}{8}$-in. width but this is about the limiting dimension. We have used only paper-base gages thus far, but if they prove to be too short-lived for a permanent installation such as this, Bakelite-base gages should prove satisfactory.

The modulus of the material in the absorption dynamometer restraining links was carefully determined by means of a Baldwin-Southwark universal testing machine. The strain gages were mounted on each side of the link and were connected in series in the bridge circuit in order to eliminate bending effects. (See frontispiece for view of strain-gage equipment.) As explained previously, one set of torsion meter links was then calibrated by connecting the torsion meter directly to the dynamometer and establishing a constant to convert from strain indicator readings to input torque. This procedure will not be necessary for other sets of torsion meter links, because the constant will vary with the area and modulus, and the modulus of the new torsion meter links can be checked in the same manner as the dynamometer links.

One of the most important of the many factors mentioned at the beginning of this report as affecting worm-gear capacity is the lubricant, and the performance of the lubricant depends, to considerable extent, on its temperature. A fairly recent improvement in the design of worm-gear units is the use of fans on the high-speed shaft for cooling the lubricant reservoir. Although considerable increase in capacity over noncooled units is claimed by manufacturers, few data seem to be available in regard to the effect of lubricant temperature and viscosity on power-transmission capacity. It is a relatively simple matter to pump the lubricant from the unit through a heat exchanger and maintain a constant temperature regardless of load. We have so arranged our test units and are running a series of tests at a constant speed and at various temperatures. The load is increased until the efficiency as calculated by measurement of input and output power reaches a maximum and begins to fall off. Plotting the input powers at which these peaks occur against the corresponding temperatures shows the effect of the temperature on the power rating.

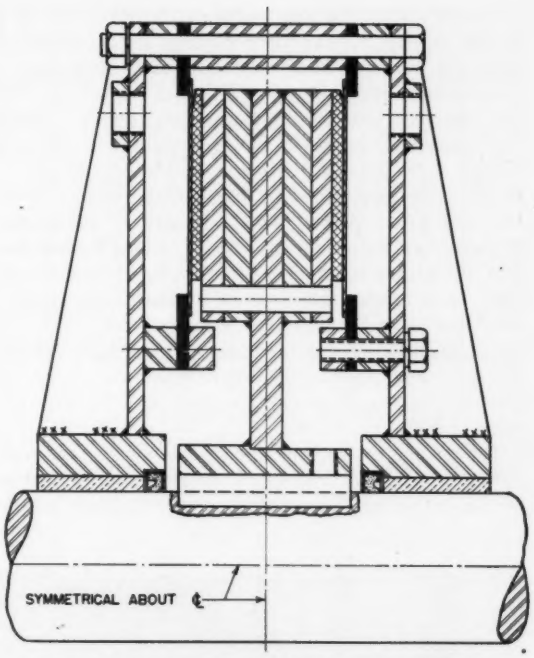


FIG. 3. PARTIAL SECTION THROUGH ABSORPTION DYNAMOMETER

The unit we are testing is a Foote Bros. HGS-7 which was available from war surplus. It is a 33 to 1 reduction, rated 11 hp at 2,000 rpm, AGMA Class 4. The center distance is $7\frac{1}{4}$ in. and the worm is a single thread with a 1-in. pitch. This is not an ideal unit for testing but will suffice to "run in" the test equipment and perfect test procedures and operation.

We have made a number of runs at 1,000 rpm and at temperatures of the 600W lubricant varying from 120° to 180°. Typical curves of horsepower input

versus efficiency for four different temperatures are shown in Fig. 5. The horsepowers at the peaks of these curves have been plotted against temperature for another curve (Fig. 6). This has been done with the idea that the maximum power rating of a unit consistent with a satisfactory life should be directly related to the type of lubricant used, the temperature that can be maintained by the cooling system used, and the input power which results in maximum efficiency at that temperature. It seems reasonable that a decrease in efficiency caused by an increase in load at a given temperature indicates decreasing effectiveness of the lubricant, and results in increased wear. The relationship between nominal power rating and power at maximum efficiency can, of course, be established only by extensive wear tests or observations of units in service.

It has been interesting to note the consistency with which runs can be duplicated, since this is, of course, an indication of the accuracy and reliability of the test equipment and methods of operation. We have found that the curves duplicate in shape rather well, although occasionally some scatter in the points and some shifting up or down occurs. We believe that this is caused primarily by difficulty in duplicating the exact conditions of a given run. Not only must the lubricant temperature be duplicated but also the temperatures of the gears. For instance, different results will be obtained for two runs at 140° if one is run soon after a cold start and the other after cooling the lubricant down soon after an extensive run, say, at 160°. It will probably be necessary to attempt to measure the material temperatures as well as the lubricant temperature. Moreover, a change in efficiency of two per cent that may appear to be quite significant may be caused by entirely reasonable variations of only one per cent in calculating input and output power.

As we have not yet run at the rated speed of the unit, no comparisons between our test results and

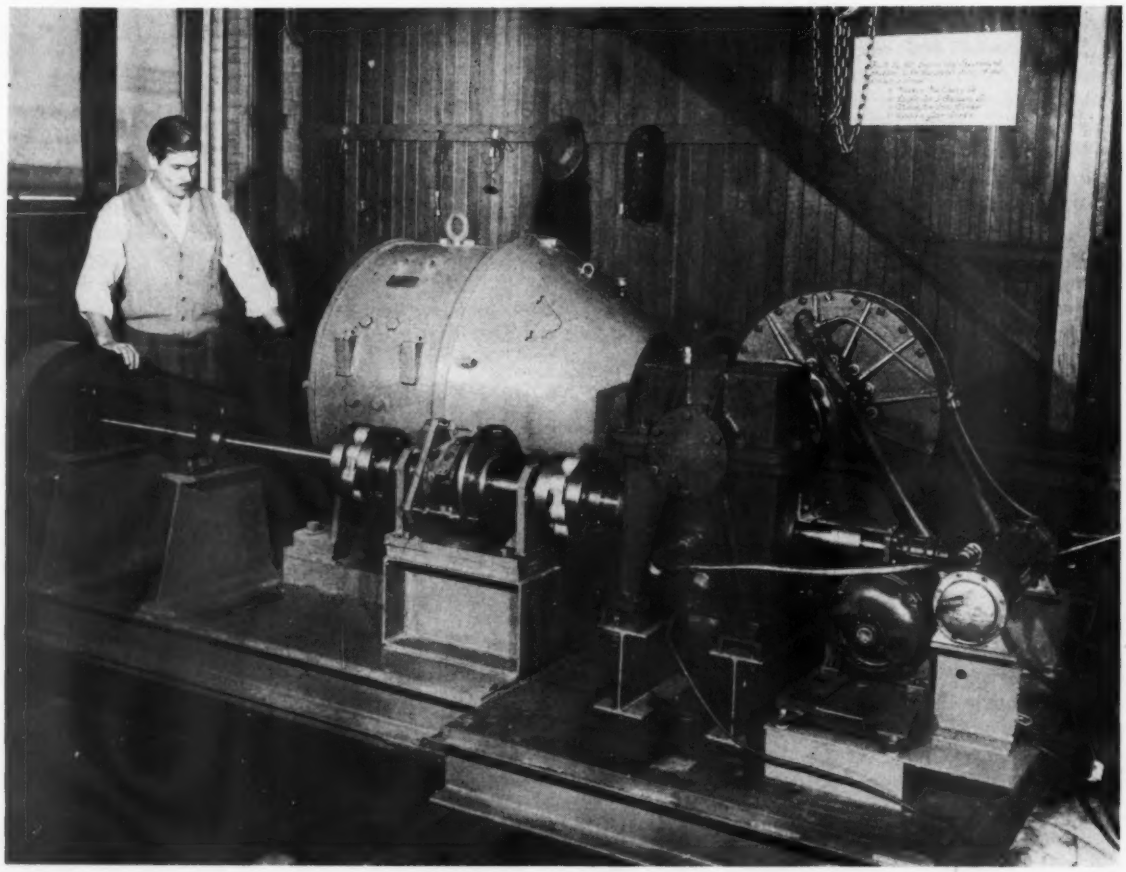


FIG. 4. VIEW OF COMPLETE UNIT

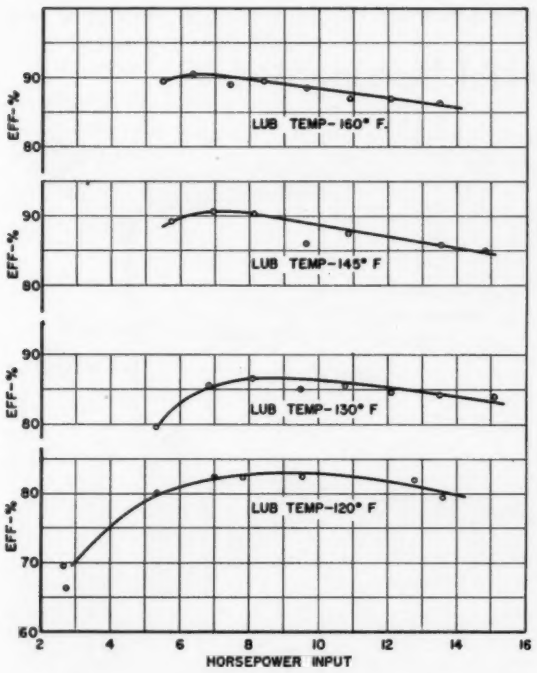


FIG. 5

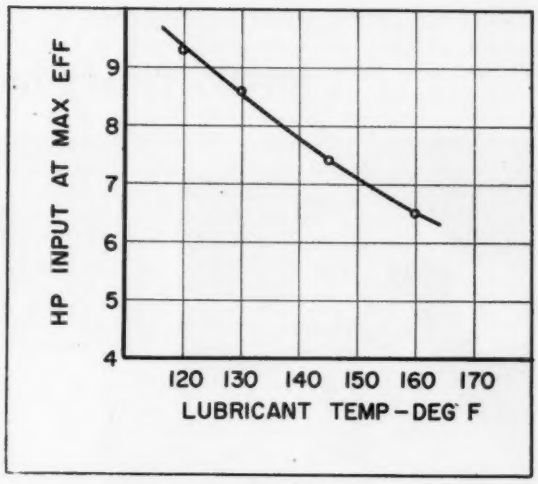


FIG. 6

the horsepower rating of the unit can be drawn. One run was made at 1,000 rpm with no lubricant cooling and with the temperature of the ambient still air at 75°. At 5.2-hp input the lubricant attained a constant temperature of 200° and the efficiency was 91 per cent.

The tests which we expect to continue on this unit and on others more suitable, varying speed, type of lubricant, etc., will furnish opportunity for students to design and operate special test equipment, establish test procedures, and analyze test results. They should also provide data of interest and value to the gear-making industry and contribute to efforts to establish improved gear-rating formulas.

NEW SERIES OF INVESTIGATIONS PLANNED BY BONNEVILLE ADMINISTRATION

The Bonneville Power Administration operates one of the largest high voltage power networks in the world and, as a consequence, encounters transmission-line relaying problems of greater than usual complexity. For the information of the uninitiated, the transmission-line relays are the devices which control the oil switches at each end of a high voltage line, causing the switches (or oil circuit breakers) to disconnect the line section from the rest of the system in the event of trouble. "Trouble" in almost 95 per cent of the cases means a short circuit resulting from a lightning stroke.

For the past two summers the writer has been employed by BPA to study the special relaying problems involved in their system. At the present time the Bonneville Power Administration has announced its intention to enter into a research and development contract with the University to carry on with investigations relating to relay problems.

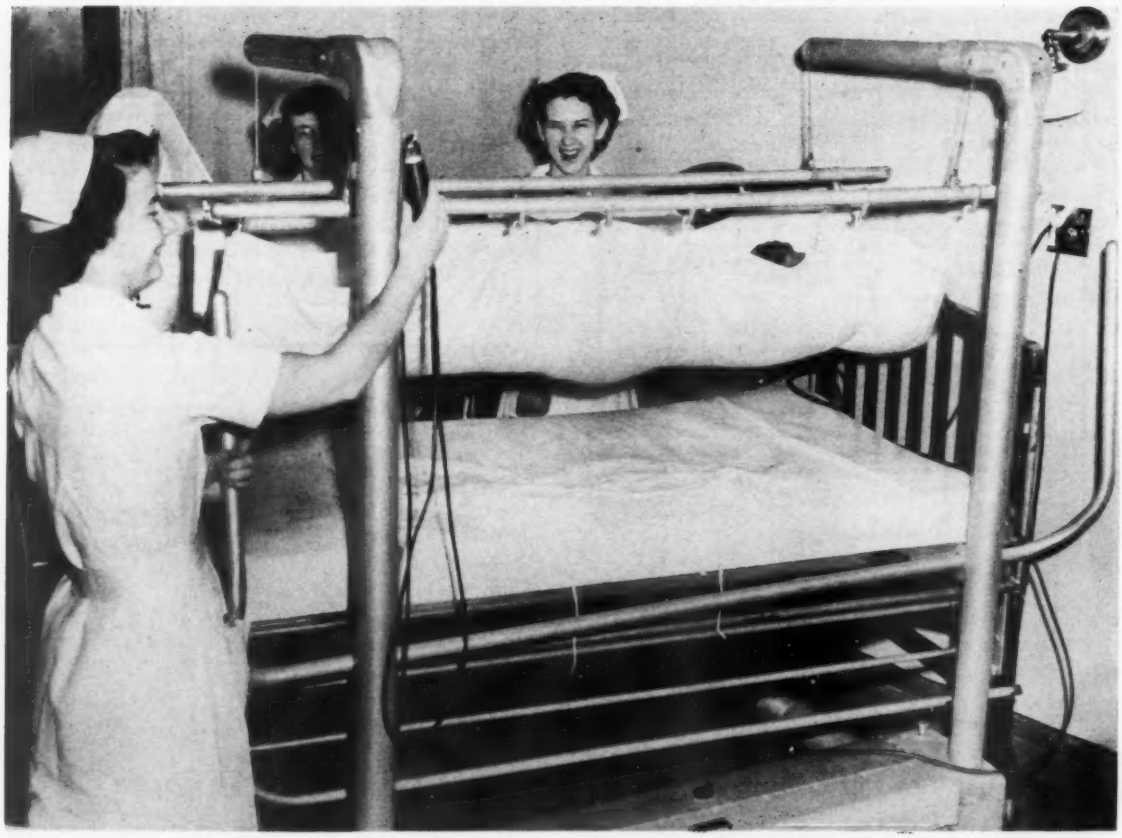
Among the investigations contemplated will be the case of relaying a line with series capacitor compensation. The first such installation at 230 kv will shortly be cut into service at Chehalis, Washington. Relaying a series capacitor compensated line has long been a problem beset with serious difficulties when approached by conventional methods.

Another phase of the University research will be directed toward the use of the new microwave communication facilities, just placed in service this year, for relay purposes. A whole new approach to the relaying art should be possible with the advent of reliable communication channels independent of the power lines themselves.

As with any research project the possible avenues through which this project may lead are as yet unknown, but the problems give promise of considerable interest.

F. R. BERGSETH
Assistant Professor of Electrical Engineering

Invalift Proves Successful Nursing Aid



INVALIFT AT PROVIDENCE HOSPITAL SHIFTS PATIENT FROM BED TO WHEELCHAIR
Photo courtesy of Seattle Post-Intelligencer

THE INVALIFT, a machine now being used in two Seattle hospitals for moving patients about, was invented by William Hanen and developed with the advisory assistance of the Engineering Experiment Station.

In the spring of 1949 Mr. Hanen came to the Engineering Experiment Station with several redesign problems. A list of engineers was supplied by the Station, and from it Mr. Hanen selected Mr. B. W. Owens, an instructor in mechanical engineering, as advisor. Together they worked on weight reduction, cost reduction, and specification of materials. By the end of 1949 the production model was completed, and during 1950 the machine was manufactured by Duralift, Inc. It was displayed at the 1950 convention of the Association of Western Hospitals.

The Invalift is movable on wheels, but has a sturdy base and leverage enough to lift the heaviest patient as cargo is lifted from the hold of a ship. The "cargo net" of strongly webbed fabric is placed under the patient, attached to the lifting cables, and "hoisted above deck." The machine is guided by a control switch in the nurse's hand. She carries out the lifting operation as casually as she would tidy up the night-table.

The patient may also be weighed by means of a balanced scale on the carriage of the Invalift machine. Because the scale eliminates any pivotal friction loss, accuracy within one-half ounce from zero to 1,000 pounds is assured. The patient may be moved from one bed to another or from his bed to a stretcher-cart, and by suspending him in mid-air the nurse

can change the bed linen without assistance from other members of the staff.

Before the Invalift was installed, the job of lifting an immobilized patient required four nurses. It called for immoderate exertion on the part of the nurses and often caused the patient to feel insecure while he was being lifted. The work now is done by the Invalift with comfort for both patient and staff.

The Engineering Experiment Station never undertakes a product development. Mr. Hanen's problem required little engineering research, and could be carried out on a part-time and extracurricular basis. In such cases the Engineering Experiment Station is prepared to supply the names of engineers, both at the University and those in private practice in the Northwest, who may provide their services for developing new products.

Steam Plant Would Save Fish and Relieve Power Shortage

THREE UNIVERSITY OF WASHINGTON faculty members were included in a party of scientists who appeared at a hearing before the Federal Power Commission in Washington, D. C., November 5 to 15, 1950, relative to the application of the City of Tacoma to construct two dams on the Cowlitz River in Southwest Washington.

Dr. Richard Van Cleve, Acting Director of the University School of Fisheries and Dr. L. R. Donaldson, Director of the University Applied Fisheries Laboratory, appeared as expert witnesses and consultants on fish biology, and the undersigned, of the Department of Electrical Engineering, appeared as an expert witness and consulting engineer for the group opposing the granting of the application. The City of Tacoma was represented by its own engineering staff, representatives of two eastern consulting engineering firms and several individual consulting engineers and biologists. Opposing the granting of the application were a number of departments of the Federal Government and the State of Washington in addition to numerous civic groups. Included were the Federal Fish and Wildlife Service, State of Washington Department of Fisheries, State of Washington Department of Game, Washington Sports Council, Oregon Fish Commission, California Fish and Game Department, Alaska Territorial Department of Fisheries, Pacific Marine Fisheries Commission, and the Fisheries Research Institute of Alaska. The Attorney General of the State of Washington was also represented because the Cowlitz River was made a fish sanctuary by the 1949 session of the State Legislature (Laws of 1949, Chapter 9).

The Cowlitz Project would consist of two hydroelectric dams: one at Mayfield, near the town of Mayfield in Lewis County, and another 13½ miles upstream. The Mayfield dam would require a fish ladder 185 feet high and would flood 13½ miles of river or 2,200 acres; Mossy rock dam would require a fish ladder 325 feet high and would flood 21 miles of river or 10,188 acres. The combined power output initially would be 345,000 kilowatts.

It was contended that the provision proposed by the applicant for passage of spawning salmon upstream, and the fingerling migrants downstream is inadequate and would destroy the annual salmon run. It was further contended that, should the salmon succeed in negotiating the barriers, their spawning grounds above the dams would be submerged and destroyed. This would end the last great spawning ground in the Pacific Northwest and affect the fishing industry from the Golden Gate to the Gulf of Alaska. In addition to the many millions of dollars lost in the fishing industry there would be a serious depletion of sport fishing in the Pacific Northwest.

A report presented by the undersigned at this hearing showed that:

1. Hydroelectric dams which destroy fish sanctuaries should not be built before approximately 30,000 kilowatts of feasible projects in the Pacific Northwest not now developed are utilized.

2. Other hydroelectric sites with approximately the same power potential and the same advantages as the Cowlitz Project but which will not harm the fish runs are available to the applicant. The North Fork of the Lewis River and the South Fork of the Snohomish were specifically mentioned.

3. An additional source of power might be obtained by construction of a steam electric-power plant. A detailed economic analysis showed that such a plant could be built to deliver power at about the same price as the Cowlitz Project. The steam power plant would have the additional advantages that it would utilize cheap fuel, could be built in less than half the time as the Cowlitz Project, and could be built at about one-third the capital cost.

The economics of the steam power plant and its place in the development of the power system of the Pacific Northwest have been under study at the University of Washington for over a year and the results are expected to be published as an Engineering Experiment Station report at an early date.

FLOYD D. ROBBINS
Instructor in E'ectrical Engineering

The Fallacy of the Best Two Out of Three

(Technical Report 1450, National Bureau of Standards, U.S. Department of Commerce)

In scientific and engineering investigations a single measurement of an unknown quantity is seldom considered sufficient. Two or more measurements are usually made in order to establish a check on instrumental errors, operator's errors in making readings, and the reliability of the sample. These multiple measurements have two principal advantages: they reveal by their concordance the precision of the measuring process, and they make possible the use of an average of several measurements which will, in general, have a higher precision than one measurement alone. If three measurements are made, it is fairly common practice for students to take the "best two out of three"—averaging the two values closest together and discarding the other. Recently, however, Dr. W. J. Youden of the Statistical Engineering Laboratory at the National Bureau of Standards has shown that this procedure very often leads to less precise results than the averaging of all three measurements together.

Experimental work frequently creates new situations in which the precision of the observations is not known in advance and must be determined from the same data that establish the estimated or average value assigned to the quantity being measured. While a single measurement cannot yield any estimate of the reproducibility of the value, two measurements do give a primitive indication of their precision. But in an entirely new experimental situation, two measurements may not give a reliable estimate of the precision, since any marked disagreement between the two readings may be due either to the inherent crudeness and inaccuracy of the measurement process or to some accident, such as the gross misreading of an instrument scale, which makes at least one of the measurements greatly in error. With two discordant observations and no other information it is impossible to decide between these alternative interpretations.

Three measurements is the minimum number that can conceivably reveal one of the measurements to be unreliable in a new experimental situation. Intuition suggests that if two of the three measurements are in close agreement while the third stands apart considerably removed from either of the others, then there may be grounds for suspecting and perhaps rejecting the third value. In terms of the difference between the two in good agreement how different may the third measurement be before it should be suspected? Since this problem is important to all who make and interpret measurements, it is a little surprising that an answer has only recently been found.

An approximate solution has been obtained in the Bureau's Statistical Engineering Laboratory through an empirical study of triads drawn at random from a large group of measurements constructed to conform to the characteristics of a normally distributed set entirely free from any gross errors. In this way, it is possible to examine a great many sets of three measurements and to determine, for example, how often the two differences between adjacent values in a set of three measurements will bear a ratio of 5 to 1, 10 to 1, 20 to 1, or any other ratio that might be considered unlikely in the normal course of events. If only 1 out of 100 sets of three measurements contained a measurement differing from the others by as much as five times the difference between the two closest, then such an observation might reasonably be discarded in actual experimental data. But the empirical study actually showed that a rather unbalanced spacing between three measurements occurs quite frequently. In fact, the ratio of the two differences was as much as 16 to 1 in 10 per cent of the sets of three measurements. In this connection, it is important to note that high ratios can result when two of the readings are very close or coincident while the third is not far removed.

The mathematical solution of this problem has been obtained and the frequency of occurrence for various ratios of the two differences has been calculated. The following table shows for certain ratios the results of an empirical sampling study of 400 sets of three measurements compared with those predicted by the exact mathematical solution of the problem.

Ratio of large to small difference	*Frequency in 400 sets*	*Theoretical frequency*
4.0 or more	149	145.2
9.0 or more	76	69.4
19.0 or more	38	33.9

These results reveal that in an average of one out of every twelve sets, one of the measurements will be at least 19 times farther away from its neighbor than the difference separating the two closest. Since in every 12 sets 1 shows such a spacing for measurements with no gross observational errors, it appears that measurements which should be retained are often dropped from the record. The problem of deciding on standards for the rejection of observations is one of long standing. Statisticians are again attacking this problem and, in the light of recent advances in the theory of small samples, considerable progress can be expected.

Engineering Research Dividends

Recent theses for advanced degrees, which were submitted as reports on Engineering Experiment Station research projects, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station.

LOO, T. S., "Effects of Temperature and Strain Rate on the Engineering Properties of Metals." M.S. in Mechanical Engineering, 1949.

This thesis presents a general survey and brief review of the existing knowledge of the temperature and strain-rate effects on the engineering properties of metals. Creep is considered from a metallurgical standpoint as a combination of plastic deformation of the grains due to the action of stress and viscous flow of the boundaries as a result of the action of hydrostatic tension. Creep is also interpreted from the viewpoint of chemical rate theory or statistical mechanical theory of shear rates. The yielding stress, σ, at a given temperature is shown to be a function of u, ϵ, and t, the expression for which is

$$\sigma = f(\epsilon, u, t),$$

in which u is the rate of deformation, t is the time and ϵ is the strain. The effects of straining rates are approached analytically from the standpoint of elastic deformation waves. Correlation between temperature and strain rate is considered embodying the concept of velocity modified temperature. The author supports his beliefs that the critical velocity of impact of a material can also be determined by means of extrapolation of slow loading results. A very extensive bibliography of some 245 references on this subject is included.

POPE, B. J., "Fischer-Tropsch Synthesis Using a Fluidized Catalyst Bed." M.S. in Chemical Engineering, 1949.

To study this reaction, a vertical tubular glass reactor was constructed, suitable for testing fluidized catalysts over a wide range of temperature, space velocity, and synthesis gas composition. Two cobalt-thoria-magnesia catalysts, supported on silica gel, were prepared, containing 26 and 52 per cent cobalt. Of these two, the latter was the more active, producing 32 grams of liquid hydrocarbon and 27 grams of methane per cubic meter of synthesis gas. The best conditions were found to be 181° C and a space velocity of 100 volumes of synthesis gas per volume of catalyst per hour, with a carbon monoxide to hydrogen ratio of 2:1. Two iron catalysts were prepared, but were inactive at atmospheric pressure. These possessed good fluidization characteristics, however, and it is possible that increased pressure would enhance catalytic activity. Electron microscope observation of three of the catalysts was made, as well as of the silica gel used as support, but it was impossible to correlate this with catalytic activity.

HAGER, R. W., "Wave Form in Shoaling Water." M.S. in Civil Engineering, 1950.

One step in the design of water-front structures is the determination of forces exerted by water waves on such structures. The present investigation was concerned with wave properties after the deep water wave form has been modified by the effect of a shoaling bottom. Model waves were generated by the flexible plate generator developed in previous studies here, and were directed over a false bottom in the wave channel. The measured wave length and wave velocity were in good agreement with present theory for bottom depths down to around 15 per cent of the wave length. The data indicated need for revising theory with respect to shallow water wave height, which was in all cases slightly less than the theoretical value. It was observed that the wave front was steeper than the reverse slope, and that the midpoint of the surface wave was elevated above the still-water level by more than the theoretical values. These findings suggest that existing theory does not make sufficient allowance for mass transport velocity.

New Research Projects

Project No. 86. Hot Process Forming of Brick and Other Heavy Clay Products. P. D. Johnson, Assistant Professor of Ceramic Engineering, Supervisor; H. A. McDonald, Research Fellow.

Project No. 87. Utilization of Olivine as a Raw Material for Ceramic Bodies. G. S. Schaller, Professor of Mechanical Engineering, Supervisor; A. M. Nelson, Research Fellow.

Project No. 88. Lateral Buckling of Rolled Steel Beams. R. A. Hechtman, Associate Professor of Structural Research, Supervisor; J. J. Miles, Research Fellow. Sponsored by Column Research Council.

Project No. 89. A Direct Method for Solving Torsion-Flutter. R. M. Rosenberg, Associate Professor of Aeronautical Engineering, Supervisor; K. P. Abichandani, Research Fellow.

Project No. 90. Investigation of Concretes Used in the Manufacture of Concrete Products. W. R. Mason, Assistant Professor of Civil Engineering.

Project No. 91. Formation of Feldspar in Granite. G. E. Goodspeed, Professor of Geology, Supervisor; H. W. Smedes, Research Fellow.

Project No. 92. Design and Development of an Internal Combustion Free Piston Air Compressor. W. B. Nordquist, Assistant Professor of Mechanical Engineering, Supervisor; F. B. McKee, Research Fellow.

Project No. 93. Convective Diffusion in Electrode Processes. R. W. Moulton, Associate Professor of Chemical Engineering, Supervisor; C. S. Lin, Research Fellow.

Project No. 94. Heat Transfer Studies in Spray Drying. R. W. Moulton, Associate Professor of Chemical Engineering, Supervisor.

Project No. 95. Kinetic Study of Anode Reactions. G. L. Putnam, Research Associate, Engineering Experiment Station, Supervisor.

Project No. 96. Air Pollution. R. G. Tyler, Professor of Sanitary Engineering, Supervisor; W. J. Montgomery, Research Fellow.

Project No. 97. Heat Transfer to Natural Circulation Vertical Tube Reboilers. R. W. Moulton, Associate Professor of Chemical Engineering, Supervisor; B. S. Pope, Research Fellow.

Project No. 98. Adsorption of Hydrocarbons on Activated Charcoal. R. W. Moulton, Associate Professor of Chemical Engineering, Supervisor; W. S. Holmes, Research Fellow.

Project No. 99. Electrolytic Production of Dithionite Salts. G. L. Putnam, Research Associate, Engineering Experiment Station, Supervisor; A. W. Werry, Research Fellow.

Project No. 100. Prediction of Plate Efficiencies in Sieve-Plate Columns. F. B. West, Assistant Professor of Chemical Engineering, Supervisor; F. Shimizu, Research Fellow.

Project No. 101. Some Aeroelastic Considerations Arising in Aircraft Design. H. C. Martin, Associate Professor of Aeronautical Engineering, Supervisor; R. B. Trefny, Research Fellow.

Project No. 102. Flow Over Cones in Supersonic Flow. R. E. Street, Associate Professor of Aeronautical Engineering, Supervisor; E. W. Radany, Research Fellow.

Project No. 103. The Dynamics of A Slender Missile Capable of Roll. R. M. Rosenberg, Associate Professor of Aeronautical Engineering, Supervisor; K. E. Alter, Research Fellow.

Project No. 104. Analogue Computer. T. M. Stout, Instructor in Electrical Engineering, Supervisor; E. F. Korn, Research Fellow.

Project No. 105. Prestressed and Post-stressed Concrete Slabs and Beams. R. A. Hechtman, Associate Professor of Structural Engineering, Supervisor; D. B. Ratti, Research Fellow.

Project No. 106. Development of Interferometer for Calibrating Strain Gages. E. E. Day, Assistant Professor of Mechanical Engineering, Supervisor; A. S. Kobayashi, Research Fellow.

Project No. 107. Determination of $P + Q$ by Optical Methods. E. E. Day, Assistant Professor of Mechanical Engineering, Supervisor; E. J. Duvall, Research Fellow.

Project No. 108. Nodular Cast Iron. Wm. A. Snyder, Assistant Professor of Mechanical Engineering.

Project No. 109. Effects of Light Hammering on Steadily Stressed Members. B. D. Mills, Professor of Mechanical Engineering, Supervisor; D. G. Harshmann, Research Fellow.

PUBLICATIONS

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56. Constant Flow Characteristic of the Plane Orifice in Proximity to Side Walls. Charles William Harris. 18 pp. 1931.
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